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Ecological assessment and suitability ranges of Ban oak (*Quercus oblongata* D. Don) in Chamba district, Himalayas: implications for present and future conservation

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Abstract

Quercus oblongata D. Don is a multipurpose tree of ecological and economical importance. Continued overuse for forage and fuel purposes has resulted in the rapid decimation of its natural habitats. Therefore, the present study was undertaken to assess the population status, regeneration pattern, and habitat suitability model (in present and future) of *Q. oblongata* in the temperate forest ecosystem of the northwestern Himalaya. We sampled 14 populations, representing 3 major habitats and 6 aspects between 812 and 2266 m amsl and with 14°–65° slope, to determine nonparametric measures of diversity. In total, we recorded 188 species (Trees: 30; Shrubs: 33 and Herbs: 125) belonging to 162 Genera and 66 Families. Density of *Quercus oblongata* ranged between 90 and 580 Indha^{-1}. Total basal area varied from 11.18 to 80.95 m^{2}ha^{-1}. The concentration of dominance varied between 0.31 and 0.99. *H*' of trees varied from 0.07 to 0.49. The MaxEnt model calibration test yielded satisfactory results (AUC$_{mean}$ = 0.825 ± 0.02). The mean temperature of the wettest quarter (BIO_09) was the most influential variable and had a permutation importance of 71.40%. The model identified an area of 1865 km^2 as high suitable for the reintroduction of *Q. oblongata*. In the CCSM4 model, future projections for RCP 4.5 and 8.5 (2050 and 2070, respectively) are remarkably close to the present distribution. Total above ground biomass density ranged from 13.01 to 164.94 Mgha^{-1}. Total below ground biomass density from 3.77 to 61.53 Mgha^{-1} and total carbon density ranged from 8.39 to 106.39 Mgha^{-1}. In conclusion, our study identified factors that define environmentally suitable areas for the occurrence of *Q. oblongata*, representing the first distribution model for the Chamba district. These findings can be used to guide government policies to protect this species.

Keywords Carbon stock · Climate change · Ecological niche modelling · MaxEnt · Population ecology

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1 Introduction

Global biodiversity is under massive pressure due to changes in land-use patterns, climatic scenarios and socio-economic components (Keenan et al. 2015). Extreme developmental activities over the last few decades have adversely affected the forest ecosystem and left behind forests that are highly fragmented and noncontiguous (Mir et al. 2020), which hinders the patterns of plant dispersal, encourages genetic drift and induces invasion of alien species (Laurance et al. 1998). Anthropogenic activities have escalated the rate of habitat destruction, according to a several research (Kardol and Wardle 2010). In general, increasing population and pollution coupled with climate change throughout the world had severely affected the global biodiversity. Several man-made activities also altered the diversity and distribution of many species of Himalayas (Dawson et al. 2011). Unsustainable extraction (for fuel and fodder) from the forests, establishment of Hydro-project stations, rapid urbanization, over grazing in the core areas of a reserve forest, forest fire, etc. resulted in the sharp decline of biodiversity in the Indian Himalayan region (IHR). These reasons also influence the growth, distribution and regeneration of *Quercus oblongata*.

In the IHR, there are some studies on ecology, floristic diversity, species composition and distribution, forest vegetation had been done so far (Dhar et al. 1997; Samant et al. 1998; Joshi and Samant 2004; Samant and Joshi 2004; Pant and Samant 2012; Sharma and Samant 2013; Devi et al. 2019; Lal and Samant 2019; Barman et al. 2021). However, only a few studies concern regarding population ecology and habitat distribution modelling (Barik and Adhikari 2012; Adhikari et al. 2012, 2018; Yang et al. 2013; Lal and Samant 2015, 2017, 2019; Paul et al. 2018; Lal et al. 2020) in the northwestern Himalayas had been carried out. The fact is that sufficient and adequate datasets on the Chamba district's current biodiversity are either unavailable or dispersed which is a matter of concern. Thus, conservation of depleting populations of Ban oak is a social-ecological challenge and requires an interdisciplinary approach. Therefore, a quantitative assessment of forest vegetation is essential for understanding the forest ecosystem structure, composition, and diversity, and for developing critical forest management and biodiversity conservation strategies with policies to protect the environment (Condit et al. 1998).

Himalayan ecosystems are known for the representative, natural and unique forests (Singh et al. 2021), supporting many ecologically and economically important multipurpose tree species (Paul et al. 2018). The northern Himalayas are a biodiversity hotspot comprising diverse vegetation types (Champion and Seth 1968) ranging from tropical moist deciduous forest to temperate and sub-alpine forests, grasslands, alpine scrub, and meadows (Marchese 2015; Roy et al. 2015). Temperate broadleaved evergreen forests are an important natural resource and a major component of sustenance of mountain natives of Himachal Pradesh, which is especially dominated by Oak. *Quercus oblongata* D. Don (commonly known as Ban oak) in Himachal Pradesh is a medium sized (Joshi and Juyal 2017), evergreen and keystone tree species (Dhyani et al. 2020) of Fagaceae family found between 1000 and 2500 m amsl (Rana et al. 1989; Singh and Singh 1986) with high abundance around 2000 m amsl (Singh et al. 2016a, 2016b) and dominant, climax tree species in the moist temperate forests of northwestern Himalaya (Troup 1921) (Fig. 1). Forests of Ban Oak are rich in soil organic matter, have high biodiversity, source of fuel wood and fodder, water holding capacity, and provide ecosystem services (like provisioning, regulating, supporting, etc.) that supports human well-being of mountain natives (Dhyani et al. 2020).

Forest regeneration is a fundamental feature of forest composition and structure of the species. The presence of sufficient number or populations of seedlings, saplings, and mature plants signifies successful regeneration of forest species (Singh et al. 2021; Dasila et al. 2020). Presence of seedlings and saplings under a canopy of mature forest vegetation also indicates the future structure of that forest community (Austin 1977). The size class distribution of populations within a structure

Fig. 1 Distribution of *Q. oblongata* throughout the Himalayan Region (*Source*: GBIF)

allows determination of regeneration, distribution, and future stability of tree species population in forest communities (Singh et al. 2021). Determining the distribution of seedlings, saplings, and adults, along with analysis of size class distributions, is a part of regeneration analysis and helps understand changes in soil parameters because nutrients in the soil are dependent on the vegetation structure and functioning of the forest (Han et al. 2011). Thus, a variation in soil nutrients may lead to an alteration in forest structure (Singh et al. 2021).

Population assessment, conservation prioritization and species reintroduction are the successful ecological techniques for recovering and maintaining the position of dwindled species populations, degraded habitats and ecosystems (Kuzovkina and Volk 2009; Zai et al. 2009; Rodriguez-Salinas et al. 2010; Polak and Saltz 2011; Adhikari et al. 2012). Ecological Niche Modelling (ENM) helps in identifying the suitable habitats, i.e., very high, high, medium and low potential areas for a species to grow in a geographic region and thus plays a key role in *in situ* conservation and ecosystem restoration (Adhikari et al. 2012; Singh et al. 2021). In view of this, studies are being carried out in other parts of the Indian Himalayan Region (IHR) (Lal and Samant 2015, 2017, 2019; Chettri et al. 2018; Sharma et al. 2018; Paul et al. 2018; Lal et al. 2020).

Climate change is identified as the influencing factor in shaping the future of any forest vegetation. Climate has a huge influence in forest ecosystem (Chaturvedi et al. 2011; Birch 2014; Upgupta et al. 2015; Chakraborty et al. 2018; Devi et al. 2018; Kumar et al. 2019) where changing climatic conditions is one of the most powerful drivers (Dhyani et al. 2020) and major concern of biodiversity loss affecting mountainous forest ecology (Dale et al. 2001; Ellison et al. 2017; Seidl et al. 2017). In general, studies focusing on the composition, structure, and function of forests had been done so far throughout the northwest Himalaya (Kalakoti et al. 1986; Singh and Singh 1986; Dhar et al. 1997; Joshi and Samant 2014; Rawat et al. 1999; Pant and Samant 2008, 2012; Rana and Samant 2009, 2010; Sharma and Samant 2013; Devi et al. 2019; Lal and Samant 2019; Barman et al. 2021). However, focused studies on ban oak populations have not been carried out so far in Himachal Pradesh. Therefore, in view of the various anthropogenic pressures and changing climate scenario, we carried out population assessment of ban oak forests to identify environmentally suitable areas for reintroduction and guide government policies to protect this species.

2 Materials and methods

Study area – Chamba district is extremely rich in flora and fauna due to its varied topography and climate and situated between north latitude 32° 11′ 30″ and 33° 13′ 06″ and east longitude 75°49′ 34″ and 77° 03′ 30″, with an estimated area of 6,522 km^2 and is surrounded on all sides by lofty hill ranges (Fig. 2). The territory is wholly mountainous with altitude ranging from approximately 600–6300 m amsl. Chamba the land of lord Shiva is famous for its untouched natural beauty. The district has Dalhousie, Khajjiar, Chamba Town, Pangi and Bharmour as main tourist destinations. There are five lakes, five wild life sanctuaries and countless number of temples. The summer season in Chamba starts from the middle of April and lasts till the last week of June. Rains in Chamba start in the month of July, when the monsoon breaks-in, and continue till late August or mid-September. The winter season in Chamba starts in the month of December and lasts till the month of February. The vegetation mainly comprises of sub-tropical, temperate, sub-alpine and alpine types.

Site selection, surveys, sampling, identification, and data analysis – The sites were selected and field surveys were conducted on each and every accessible aspect along the topographical gradient between 812 and 2266 m amsl in the ban oak forests. Information on the habitat type and site characteristics, i.e., altitude, latitudes, and longitudes of each sampled plot were obtained with the help of Global Positioning System (Garmin Montana 650). The slope and aspects were measured by Clinometer (some sites by Abney Level) and compass, respectively. The habitats were identified based on the physical characteristics and dominance of the vegetation. Sites having a closed canopy with high proportions of humus were considered shady habitats, and sites having high content of moisture as moist habitat; with boulders on > 50% of the ground cover as bouldery habitats; containing rocks as rocky habitat; and along the streams and riverbanks riverine habitat (Samant and Joshi 2004). The field surveys and samplings were conducted in the month of May 2019.

A plot of 50 × 50 m was laid. Trees, saplings and seedlings were sampled randomly by 10 quadrats of 10 × 10 m, shrubs by 20 quadrats of 5 × 5 m and herbs by 20 quadrats of 1 × 1 m size. For the collection of data from these quadrats standard ecological methods (Curtis and McIntosh 1950; Greig-Smith 1957; Kershaw 1973; Mueller-Dombois and Ellenberge 1974; Dhar et al. 1997; Joshi and Samant 2004). Species diversity (H') was calculated by using the Shannon–Wiener information index (Shannon and Wiener 1963). The concentration of dominance (Cd) was calculated using Simpson's index (Simpson 1949). The total count of species was considered as species richness.

According to field data, tree individuals were grouped into arbitrary Circumference at Breast Height (CBH) classes. The individuals with CBH of 30.5 cm or more were considered as trees, those with CBH of 10.5–30.4 cm as saplings, and those with CBH < 10.5 cm as seedlings (Dhar et al.

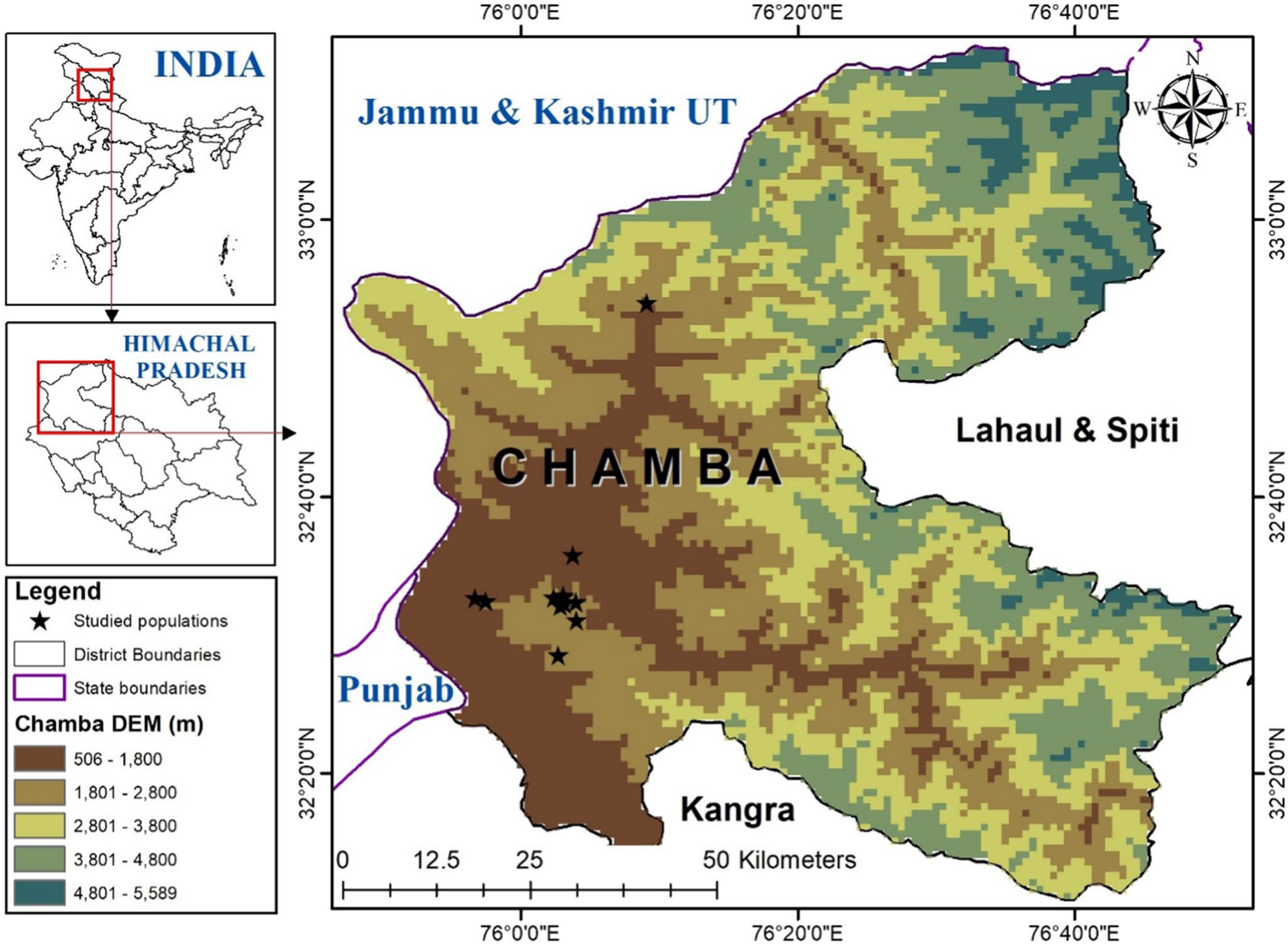


Fig. 2 Map of the study area

1997). Shrubs were considered as woody species having several branches arising from their base, and herbs were considered as those species having aerial parts surviving for one season, though their underground parts, i.e., roots/rhizomes/bulbs, etc. may remain alive during other seasons (Joshi and Samant 2004).

Three vegetation layers, i.e., tree, shrub and herb were analyzed for species richness, diversity, frequency, density, abundance, basal area (BA), total basal area (TBA), important value index (IVI) and regeneration of tree species. The abundance data of different sites were pooled to get community averages in terms of density, total basal area and IVI. Data analysis was done following Kersaw (1973); Dhar et al. (1997) and Samant et al. 2002. The size class distribution of trees, saplings, and seedlings of *Q. oblongata* was also done based on the CBH range of the tree (Singh et al. 2021). For the size class distribution profile of *Q. oblongata*, 12 CBH classes were identified, namely, < 10.5 cm, 10.5–31.4 cm, 31.5–52.5 cm, 52.6–73.5 cm, 73.6–94.5 cm, 94.6–115.5 cm, 115.6–136.5 cm, 136.6–157.5 cm, 157.6–178.5 cm, 178.6–199.5 cm, 199.6–220.5 cm and ≥ 220.6 cm. These values were used to predict the future occurrence or dominance of the species.

Assessment of Physico-chemical properties of Soil – Soil samples were collected from each studied plot of 50 × 50 m. Soil was cored up to 20 cm depth. Five soil samples, four from the corners and one from the center of each plot were collected, pooled and mixed properly to make a composite sample. The air-dried soil samples were assessed for further tests and analysis. Soil pH was measured using pH meter in 1:5 mixture of soil and distilled water, moisture content was recorded as percentage (%) difference in fresh and dry soil weight, % organic carbon and organic matter were analyzed as described by Walkley and Black method (Walkley and Black 1934), available nitrogen by Kjeldahl method (Subbiah and Asiijah 1956), available phosphorus by Olsen's extraction method (Olsen et al. 1954) and available potassium by flame photometer (Allen et al. 1974; Jackson 1958). By plotting all of the data along with the first two principal components, principal component analysis (PCA) was used to extract the most important information from the multivariate dataset.

Species distribution/habitat modelling – *Q. oblongata* is one of the dominant species in northwestern Himalaya, and hence, the distribution of species is very wide in the state having more dominance in 7 districts (namely Chamba, Mandi, Kullu, Shimla, Solan, Sirmour and Dharamshala region of Kangra). The habitat modelling (Fig. 3) was performed assuming that the species habitat suitability is influenced significantly by the climatic data (abiotic conditions) derived from temperature and precipitation. Fourteen primary distribution records of *Q. oblongata* were collected through field surveys. The coordinates of all occurrence points were recorded in decimal degree to an accuracy range of 3–5 m using a Global Positioning System.

MaxEnt (Maximum Entropy Modelling) version 3.4.3 was downloaded from the portal (https://biodiversityinformatics.amnh.org) and used for modelling (Phillips et al. 2006) with a set of 19 bioclimatic variables (Phillips and Dudik 2008). The climatic variables used to construct our ENM were defined by Terribile et al. (2012) from the factorial analysis of 19 bioclimatic variables based on a correlation matrix among them in which were chosen variables that reduced problems of collinearity. These variables were mean diurnal range, temperature seasonality, mean temperature of driest quarter, precipitation of driest month, precipitation seasonality and precipitation of warmest quarter. ENMs do not differ significantly between different global circulation models (GCM) (Barbosa et al. 2019). In this sense, the variables were estimated for the community climate system model 4 (CCSM4) which was downloaded from World Clim portal (http://www.worldclim.org/current) having 30 arc sec

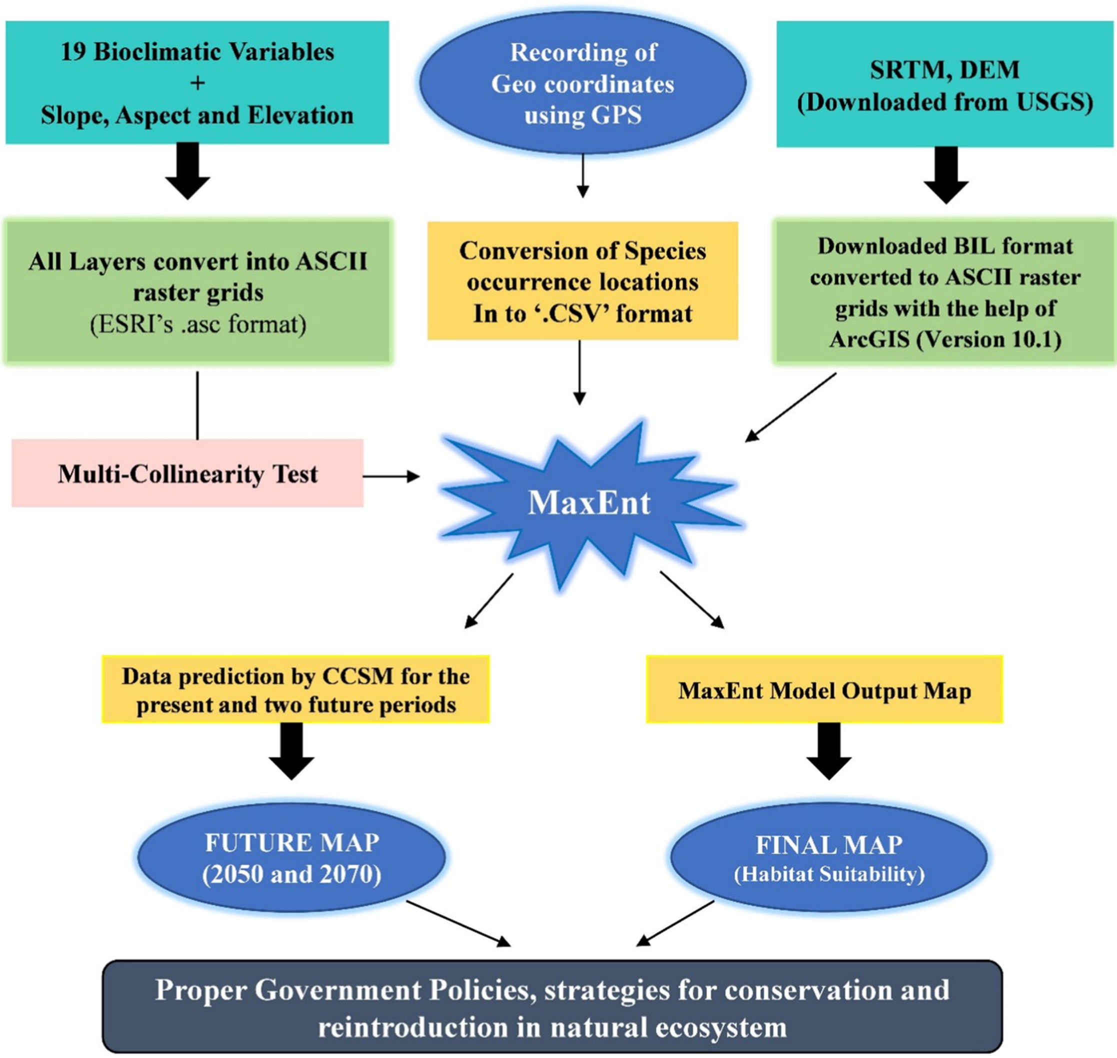


Fig. 3 The methodology of eco-distribution mapping based on MaxEnt modeling

(equivalent to 900 m at equator, ~ 1 km) resolution for the present and two future periods averaged at years 2050 and 2070.

The bioclimatic variables (Supplementary table S3) were derived from the surface temperature and precipitation observations which were widely used as environmental predictor variables in species distribution model (SDM) studies. The MaxEnt model fits a probability density function based on the values of environmental variables (bioclimatic and topographic data) observed at the species occurrence locations. Topographical data such as altitude and aspect were derived from the Shuttle Radar Topographic Mission (SRTM). Elevation data for a digital elevation model (DEM) of 30 m resolution were downloaded from the US Geological Survey (USGS) portal (https://earthexplorer.usgs.gov). Remotely sensed data on bioclimatic variables (Hijmans et al. 2017) in highest resolution (i.e., ~ 1 km) were downloaded in BIL format and converted to ASCII raster grids with the help of ArcGIS version 10.1. Resampling DEM was used to match the bioclimatic data's coordinate reference system and resolution. MaxEnt generates response curves for each predictor variable. In highlighting the relative influence of each predictor variable, the Jackknife method was used (Fielding and Bell 1997). Before running the model, the variables were checked for multi-collinearity to avoid bias (Dormann et al. 2007; Elith et al. 2010). High correlations (> 0.70) between bioclimatic variables would indicate that datasets have a similar broad scale spatial pattern. In addition, taking all default variables could lead to spurious results or obscure the effect of the most important variables (Supplementary table S4).

Records used to build the ENM were split randomly into two groups: one for calibration with 75% of the data and the other for evaluation with 25%. To validate model robustness, 15 replicated runs were performed for the species with a threshold rule of 10 percentile training presence, which omitted all regions with habitat suitability lower than that for the lowest 10% of the occurrence records. In the replicated runs, a cross-validation technique was employed, where samples were divided into replicate folds, and each fold was used for test data. MaxEnt would estimate the importance of the variables with percent contribution and permutation importance values. Percent contribution would represent how much the variable contributed to the model, based on the path selected for the particular run. The desired values along with the average model results were incorporated in ArcGIS to match the selected threshold using reclassification. Permutation importance was determined by changing the predictor values between presence and background points and observing how they affected the area under the curve (AUC). The permutation importance would include the final performance of the model, rather than the path used in an individual run, which would be useful for evaluating the importance of a particular variable. The contribution of each variable to the habitat model of *Q. oblongata* was calculated using the built-in software or "Jackknife test," which was used to determine the dominant bioclimatic factors responsible for the potential distribution of the species (Li et al. 2016).

Based on the AUC values, the quality of the model was evaluated and graded following Thuiller et al. 2005, as poor (AUC < 0.8), fair (AUC 0.8–0.9), good (AUC 0.9–0.95), and very good (AUC 0.95–1.0). The trained MaxEnt model was supplied with future environmental data representing the climate variability in order to project the future habitat suitability maps. Except for bioclimatic variables, the topographic variables were assumed to remain constant for the future projections. Arc GIS version 10.1 were used to generate predictive maps of species distribution and potential areas of distribution and reintroduction. In the present study, 10 percentile training presence logistic threshold was applied to stipulate 10 percentile minimum threshold.

Biomass Estimation – The diameter at breast height (DBH) for each tree was measured at 1.37 m above the surface. The density of trees under each DBH class was used to determine the total tree biomass value. To estimate the above ground biomass (AGB), the biomass value per tree under different DBH classes were estimated using regression equation of Chambers et al. (2001).

$$\text{AGB}: \ln = -0.37 + 0.333\ \ln D + 0.933[\ln(D)]^2 - 0.122[\ln(D)]^3$$

$$\text{Below Ground Biomass (BGB)}: \text{AGB} \times 0.29$$

$$\text{Total Biomass Density (TBD)}: \text{AGB} + \text{BGB}$$

Total carbon density (TCD) was estimated by multiplying the factor 0.5 with TBD value.

Numerical and statistical analysis – All numerical analyses were done in MS-Excel and principle component analysis using paleontological studies (PAST) package.

3 Results

Spatial pattern and distribution – In total, 14 sites representing 3 habitats and 6 aspects between 812 and 2266 m amsl and with 14–65° slope were sampled from the Chamba district. Most sites (5, each) were represented by dry and shady habitats, followed by moist (4) habitat. Six (6) sites were represented by West aspect, followed by southeast (3), east (2) and northeast, northwest and southwest (1, each) aspects. The slopes varied from 14° to 65°. Physical characteristics, dominant species, aspect, altitude, and slope of the populations of *Q. oblongata* are presented in Table 1.

Species composition of studied populations – Total 188 species (Trees: 30; Shrubs: 33 and Herbs: 125) belonging to 162 Genera and 66 Families were recorded from 14 sampled sites. Maximum species (88) (Trees: 06, Shrubs: 12 and Herbs: 70) was recorded in Dumas-Tissa, followed by Chaned (81 species; Trees: 13, Shrubs: 11 and Herbs: 57); KKWS-I (70 species; Trees: 06, Shrubs: 08 and Herbs: 56); Banikhet (69 species; Trees: 08, Shrubs: 12 and Herbs: 49) (Supplementary Fig. S1). Dominant genera were *Erigeron, Ficus, Persicaria* and *Quercus* (3 species, each); followed by *Adiantum, Anaphalis, Arisaema, Aster, Carex, Clematis, Digitalis, Galium, Geranium, Hypericum, Impatiens, Indigofera, Isodon, Pinus, Rubus, Trifolium* and *Viola* (2 species, each). Dominant family was Compositae (19 species); followed by Leguminosae (14 species); Lamiaceae (13 species); Poaceae (12 species); Rosaceae (8 species); Orchidaceae and Polygonaceae (7 species, each); Ranunculaceae and Rubiaceae (5 species, each); Amaranthaceae, Acanthaceae, Moraceae, Pinaceae and Pteridaceae (4 species, each). Monotypic families were Adoxaceae, Apocynaceae, Aspleniaceae, Linaceae, Oleaceae, Onagraceae, Saxifragaceae, Scrophulariaceae, Smilacaceae, Thelypteridaceae, Thymelaeaceae, Verbenaceae, Zingiberaceae.

Population ecology – Overall, site-wise species richness, total basal area (TBA), species diversity (*H'*), and concentration of dominance (Cd) of tree, shrub, and herb layers are presented in supplementary table S2. The richness of trees ranged from 2 (Jot and Hatli-Dramman) to 8 (Bhujnoi-Gate); shrubs from 4 (Khajjiar-I and Khajjiar-II) to 12 (Banikhet and Dumas-Tissa. each); herb richness ranged from 29 (Chaned) to 47 (Banikhet). Total trees density varied from 270 Ind ha^{-1} (Jot) to 750 Ind ha^{-1} (Banikhet), and the density of *Q. oblongata* varied between 90 Ind ha^{-1} (Hatli-Dramman) to 580 Ind ha^{-1} (Bhujnoi-Gate) (Supplementary Fig. S2). Total shrubs density varied from 1102 Ind ha^{-1} (Hatli-Dramman) to 2689 Ind ha^{-1} (Dummas-Tissa), and total herbs density varied from 31 Ind m^{-2} (Hatli-Dramman) to 85 Ind m^{-2} (KKWS I). Altitude wise density of trees, saplings and seedlings in studied populations is given in Fig. 4. TBA varied from 11.18m^2 ha^{-1} (Hatli-Dramman) to 55.67 m^2 ha^{-1} (Dummas-Tissa). TBA of *Q. oblongata* varied between 8.13 m^2 ha^{-1} (Kalatop Khajjiar Wildlife Sanctuary:

Table 1 Site characteristics and associated tree species of *Quercus oblongata* D. Don populations in the studied populations

Site no	Population	Habitat type	Altitude (m)	Aspect	Slope (°)	Latitude (°N)	Longitude (°E)	Associated tree species
01	Dumas-Tissa	Shady	1680	West	14	32° 53.957'	76° 09.112'	*Quercus glauca, Quercus floribunda, Cedrus deodara* and *Juglans regia*
02	Chaned	Dry	1128	Northwest	65	32° 35.774'	76° 03.762'	*Pinus roxburghii, Albizia lebbek, Robinia pseudoacacia, Pyrus pashia, Ficus palmata* and *Toona ciliata*
03	Banikhet	Shady Moist	1585	Southwest	30	32° 32.674'	75° 56.728'	*Rhododendron arboreum* and *Cedrus deodara*
04	Mankot	Shady	1845	West	45	32° 32.444'	75° 57.487'	*Rhododendron arboreum, Aesculus indica* and *Cedrus deodara*
05	Khajjiar-I	Shady	1861	Southeast	44	32° 32.141'	76° 02.842'	*Cedrus deodara, Aesculus indica* and *Picea smithiana*
06	Khajjiar-II	Shady	1968	West	51	32° 32.384'	76° 03.999'	*Rhododendron arboreum* and *Cedrus deodara*
07	Bhujnoi-Gate	Dry	1844	Southeast	55	32° 31.080'	76° 04.032'	-
08	Jot	Dry	2266	East	45	32° 28.547'	76° 02.710'	*Rhododendron arboreum* and *Cedrus deodara*
09	Hatli-Dramman	Shady	812	West	60	32° 13.757'	76° 10.317'	*Albizia lebbek, Bauhinia variegata* and *Mallotus philipensis*
10	KKWS-I	Shady Moist	1970	North East	60	32°32.385'	76°03.983'	*Persea duthiei*
11	KKWS-II	Dry	1980	Southeast	58	32°32.278'	76°03.161'	*Cedrus deodara* and *Picea smithiana*
12	KKWS-III	Shady Moist	1892	West	40	32°32.853'	76°03.060'	*Cedrus deodara, Lyonia ovalifolia* and *Rhododendron arboreum*
13	KKWS-IV	Dry	2009	East	50	32°32.718'	76°02.372'	-
14	KKWS-V	Shady Moist	1924	West	42	32°32.745'	76°03.121'	*Cedrus deodara*

KKWS Kalatop Khajjiar Wildlife Sanctuary

KKWS-V) and 55.67 $m^2\ ha^{-1}$ (Dummas-Tissa). The Cd of *Q. oblongata* varied between 0.31 (KKWS-IV) and 0.99 (Bhujnoi-Gate). Cd for shrubs ranged from 0.0069 (Jot) to 0.1422 (Dummas-Tissa), and herbs from 0.02 (Dumas-Tissa) to 0.30 (Bhujnoi-Gate). *H'* of trees varied from 0.07 (Dummas-Tissa) to 0.49 (KKWS-V); shrubs from 0.58 (Khajjiar-II) to 2.16 (Dummas-Tissa); and herbs from 2.21 (KKWS-I) to 4.17 (Dumas-Tissa). The shady habitat represented maximum density (536 Ind ha^{-1}), followed by moist (521 Ind ha^{-1}) and dry (418 Ind ha^{-1}) habitats. TBA was highest in shady habitat (55.32 $m^2\ ha^{-1}$), followed by moist (41.99 $m^2\ ha^{-1}$) and dry (37.65 $m^2\ ha^{-1}$) habitat.

Regeneration pattern – Total seedlings density ranged from 80 Ind ha^{-1} (Jot and Hatli-Dramman) to 370 Ind ha^{-1} (Dumas-Tissa). Seedlings density of *Q. oblongata* ranged from 40 Ind ha^{-1} (Jot) to 140 Ind ha^{-1} (Chaned). Total saplings density ranged from 30 Ind ha^{-1} (Hatli-Dramman) to 160 Ind ha^{-1} (Dumas-Tissa). Saplings density of *Q. oblongata* ranged from 30 Ind ha^{-1} (Banikhet and Hatli-Dramman, each) to 110 Ind ha^{-1} (Dumas-Tissa) (Table 2). Seedlings density and saplings density were significantly correlated ($p \leq 0.01$, $r = 0.63$, $n = 14$) throughout the sites.

Size class distribution profile of *Q. Oblongata* – The size class distribution diagram of *Q. oblongata* deviated slightly from the reverse J shape structure that is considered to

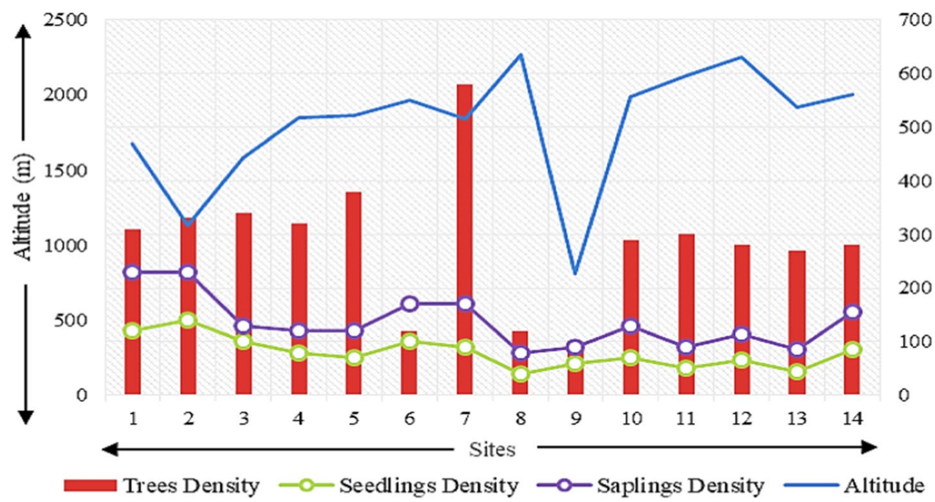


Fig. 4 Altitude wise density of trees, saplings and seedlings in studied populations

Table 2 Population wise total trees density, seedlings and saplings of *Quercus oblongata* D. Don populations

Population	Density (individual/hectare)					
	Trees		Seedlings		Saplings	
	1	2	1	2	1	2
Dumas-Tissa	400	310	370	120	160	110
Chaned	610	330	240	140	100	90
Banikhet	750	340	270	100	50	30
Mankot	730	320	190	80	60	40
Khajjiar-I	660	380	240	70	90	50
Khajjiar-II	310	120	130	100	90	40
Bhujnoi-Gate	580	580	90	90	80	80
Jot	270	120	80	40	40	40
Hatli-Dramman	390	090	80	60	30	30
KKWS-I	365	290	140	80	100	60
KKWS-II	360	300	100	80	90	70
KKWS-III	340	280	180	90	110	80
KKWS-IV	360	270	210	110	120	80
KKWS-V	380	280	220	130	100	70

1 = Total tree density and 2 = Density of *Q. oblongata*

be an indication of good regeneration status. Individuals with smaller diameter class < 10.5 cm (i.e., seedlings) and 10.5–31.4 cm (i.e., saplings) were relatively high in number, but those with diameter class between 31.5–52.5 cm were relatively fewer. Furthermore, the number of individuals in the medium girth class (52.6–73.5 cm and 73.6–94.5 cm) was higher than one would expect in a reversed J distribution. The lowest number of individuals were recorded in the 157.6–178.5 cm girth class (Fig. 5).

Physico-chemical properties of soil – Among the populations, pH was found to be slightly acidic across all elevations due to high litter decomposition and organic matter; it ranged from 6.1 (Banikhet) to 6.9 (Hatli-Dramman) which is considered as satisfactory for the growth of most of the plants in natural ecosystem. Moisture content was maximum in KKWS-IV (41.79%) and minimum in Chaned (13.25%). Total nitrogen of soil was found lowest at Chaned population (1.05%) and the highest at KKWS-V population (5.98%). Soil organic matter varied from 7.86% (Chaned) to 19.91% (KKWS-III); the total organic carbon of soil from 2.51% (Dumas-Tissa) to 9.69% (Banikhet); available phosphorus varied from 13.46 kg ha^{-1} (KKWS-II) to 71.22 kg ha^{-1} (KKWS-V); and available potassium varied from 18.42 to 51.13 kg ha^{-1} (Fig. 6). Except for moisture content and potassium, which were found in the opposite direction, it reveals that most of the soil parameters were varied in similar ways. Population wise PCA plot has indicated that Jot, KKWS II, Chaned, Bhujnoi-Gate being at the right east corner of the ordination plot, has unique set of gradients for dominance and thus does not share its habitat with other species. Similar characteristics were observed for KKWS-III and KKWS-V, which was positioned at eastern side of ordination plot (Fig. 7).

Species distribution/habitat modelling – The output generated by MaxEnt predicted suitability of habitats of the species on the scale from 0 to 1, with the least suitable areas represented by 0, and the most suitable ones represented by 1. The habitat distribution modelling calibration test for *Q. oblongata* showed satisfactory results. Receiver operating characteristic (ROC) curve displays sensitivity and 1-specificity with AUC for training (0.908) and test (0.885) where average test AUC for replicated runs was 0.825 ± 0.02. Based on permutation importance, mean temperature of wettest quarter (BIO_09) was the most influential and had a permutation importance of 71.40%, followed by DEM, with a permutation importance of 11.47%, mean diurnal range (BIO_02) (7.47%), slope (7.38%), temperature seasonality (BIO_04) (5.97%), precipitation of driest month (BIO_14) (3.75%), precipitation seasonality (BIO_15) (2.38%) and precipitation of warmest quarter (2.03%). The most important variable based on percent contribution was temperature seasonality with a contribution of 43.70% to the habitat model, followed by precipitation of driest month (31.45%), mean temperature of driest quarter (15.64%), DEM (7.50%), mean diurnal range (4.20%), slope (1.70%) and precipitation seasonality (0.36%). Precipitation of warmest quarter (0.03%) had the least influence on the MaxEnt Model (Table 3). The Jackknife plot for comparing the climatic variables in model prediction is depicted in Fig. 8. During field surveys, it was observed that *Q. oblongata* survived better only in temperate climatic conditions, and that the species preferred precipitation in the coldest quarter and grew mostly in moist habitats between 1600 and 2200 m amsl. This was validated by the model output. In the ROC analysis, performance was measured by the AUC (Fig. 9a–d).

Potential habitat distribution area – In the study area, maximum habitats with high suitability thresholds were distributed in Kalatop Khajjiar Wildlife Sanctuary area, Banikhet and Dumas-Tissa area (Fig. 10). Field surveys revealedthat the predicted potential habitats were mostly located in the shady and shady moist habitats of the studied populations

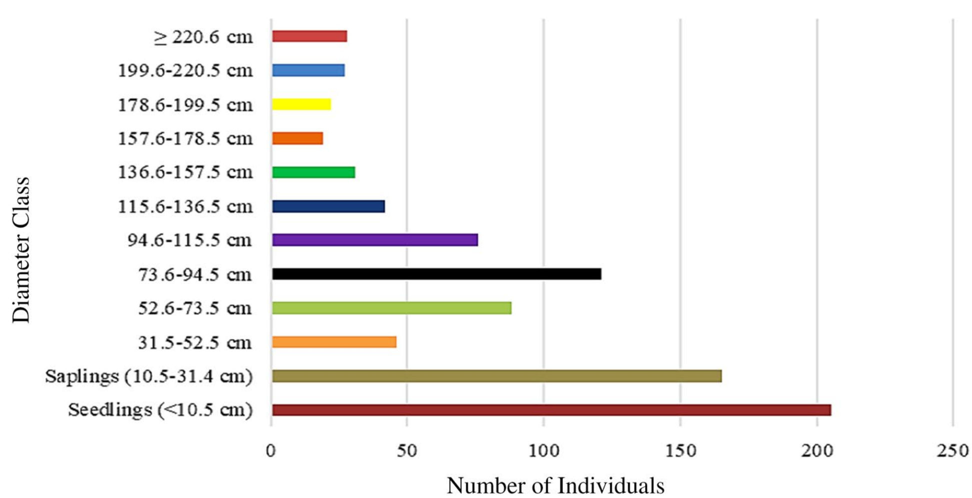


Fig. 5 Distribution of *Q. oblongata* individuals under different diameter size classes

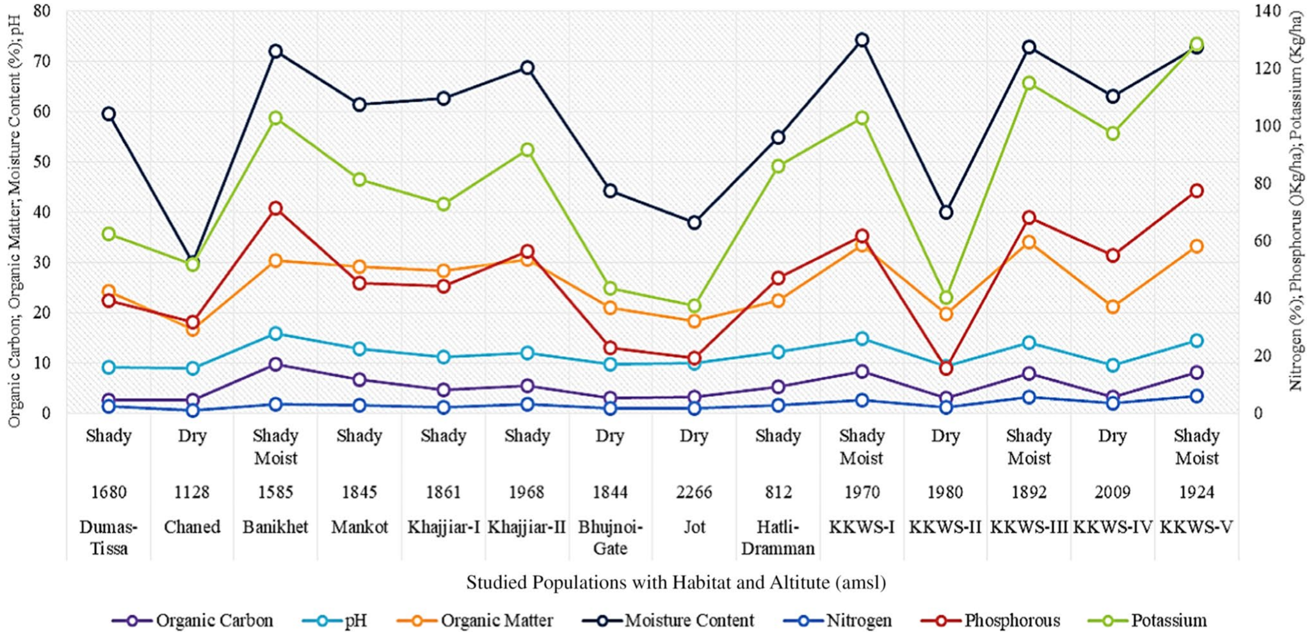


Fig. 6 Physico-chemical profile of soil in different populations

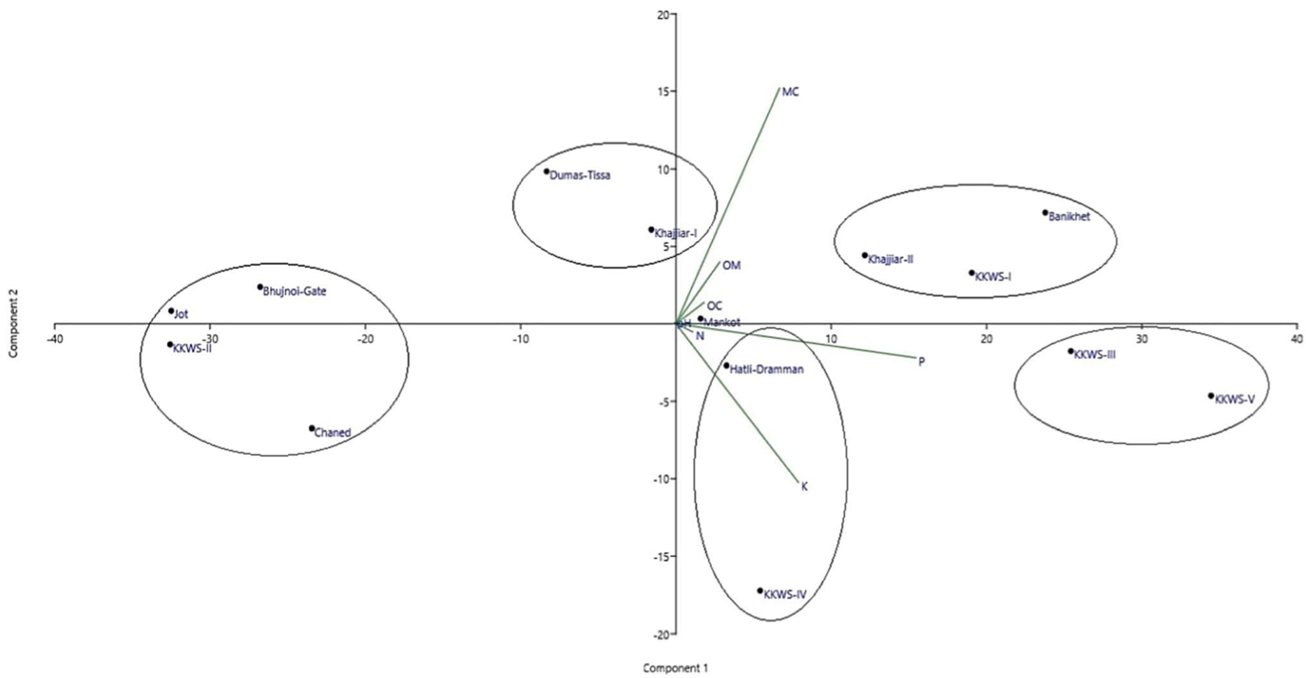


Fig. 7 Distribution of the populations represented by two principal components in PCA

in Chamba district. Of the total 6498 km^2 area, 1879 km^2 (28.91%) area was completely not suitable for natural regeneration or reintroduction while 1247 km^2 (19.19%) area was low suitable, 1507 km^2 (23.19%) area was moderately suitable and 1865 km^2 (28.70%) area with high suitability of reintroduction, natural growth and development of the *Q. oblongata* population (Supplementary Table S2).

Future projection of climatically suitable areas – In the CCSM4 model, future projections of habitat suitability

Table 3 Environmental variables and their percent contributions for predicting the potential distribution of *Quercus oblongata* D. Don

Type	Code	Name of the variables	Unit	% Contribution
Climatic	Bio2	Mean diurnal range (mean of monthly max. and min. temp.)	°C	4.20
	Bio4	Temperature seasonality (standard deviation × 100)	C of V	43.70
	Bio9	Mean temperature of driest quarter	°C	15.64
	Bio14	Precipitation of driest month	mm	31.45
	Bio15	Precipitation Seasonality (Coefficient of Variation)	C of V	0.36
	Bio18	Precipitation of warmest quarter	mm	0.03
Geomorphologic	DEM	DEM	°	7.50
	SLOPE	SLOPE	°	1.70

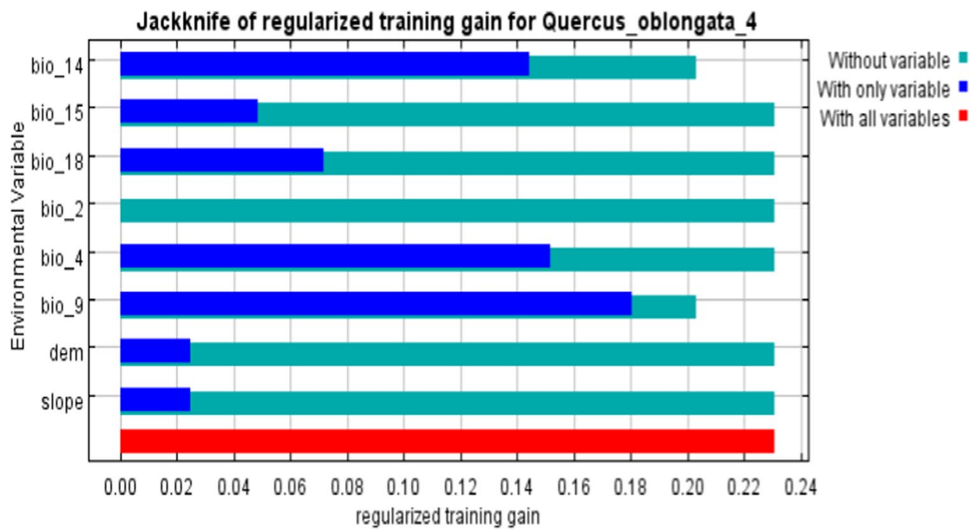


Fig. 8 Results of Jackknife test highlighting the importance of environmental variables for *Quercus Oblongata* in Chamba District

maps for Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 (2050 and 2070, respectively) were to some extent close to the present distribution. According to the current findings, if climate change occurs at expected levels (RCP 4.5 and RCP 8.5), the specie's geographic location will expand relative to its present potential distribution, RCP 4.5 anticipates an increase of 0.4 percent in habitat suitability area by 2050 and 1.4 percent by 2070, respectively, for the high habitat suitability area. 1.5 percent increase is projected in 2050, and 1.1 percent decrease is expected in 2070, according to the RCP 8.5 estimate. However, when compared to the present prediction, the potential high suitability showed higher rate of increase in both scenarios (RCP 4.5 and 8.5) for 2050, after which in scenario (RCP 8.5, 2070), it showed a decreasing trend (Fig. 11).

Biomass estimation – Total above ground biomass density (TAGBD) ranged from 13.01 to 164.94 Mg ha^{-1}. Maximum TAGBD was found in Banikhet. Above ground biomass density for *Q. oblongata* (AGBD_QO) was ranged from 10.52 to 110.80 Mg ha^{-1}. Maximum AGBD_QO was found in Dumas-Tissa. Total below ground biomass density (TBGBD) ranged from 3.77 to 61.53 Mg ha^{-1}. Maximum TBGBD was found in KKWS-I. Below ground biomass density for *Q. oblongata* (BGBD_QO) was ranged from 3.05 to 52.84 Mg ha^{-1}. Maximum BGBD_QO was found in KKWS-I. Total Biomass Density (TBD) ranged from 16.79 to 212.78 Mg ha^{-1}. Maximum TBD was found in Banikhet. Biomass density for *Q. oblongata* (BD_QO) was ranged from 13.57 to 142.94 Mg ha^{-1}. Maximum BD_QO was found in Dumas-Tissa. Total carbon density (TCD) ranged from 8.39 to 106.39 Mg ha^{-1}. Maximum TCD was found in Banikhet. Carbon density for *Q. oblongata* (CD_QO) was ranged from 6.79 to 71.47 Mg ha^{-1}. Maximum CD_QO was found in Dumas-Tissa (Table 4).

Correlation of ecological components – The statistical analysis revealed a positive correlation between density of seedlings and saplings ($R^2 = 0.5428$, $r = 0.7367$, $n = 14$, $p \leq 0.05$); TBA and altitude ($R^2 = 0.1214$, $r = 0.3484$, $n = 14$, $p \leq 0.05$); density of trees and seedlings ($R^2 = 0.1523$, $r = 0.3902$, $n = 14$, $p \leq 0.05$); density of trees and Cd ($R^2 = 0.1491$, $r = 0.3861$, $n = 14$, $p \leq 0.05$) Total trees density showed positive correlation with density of Q. oblongata ($R^2 = 0.5599$,

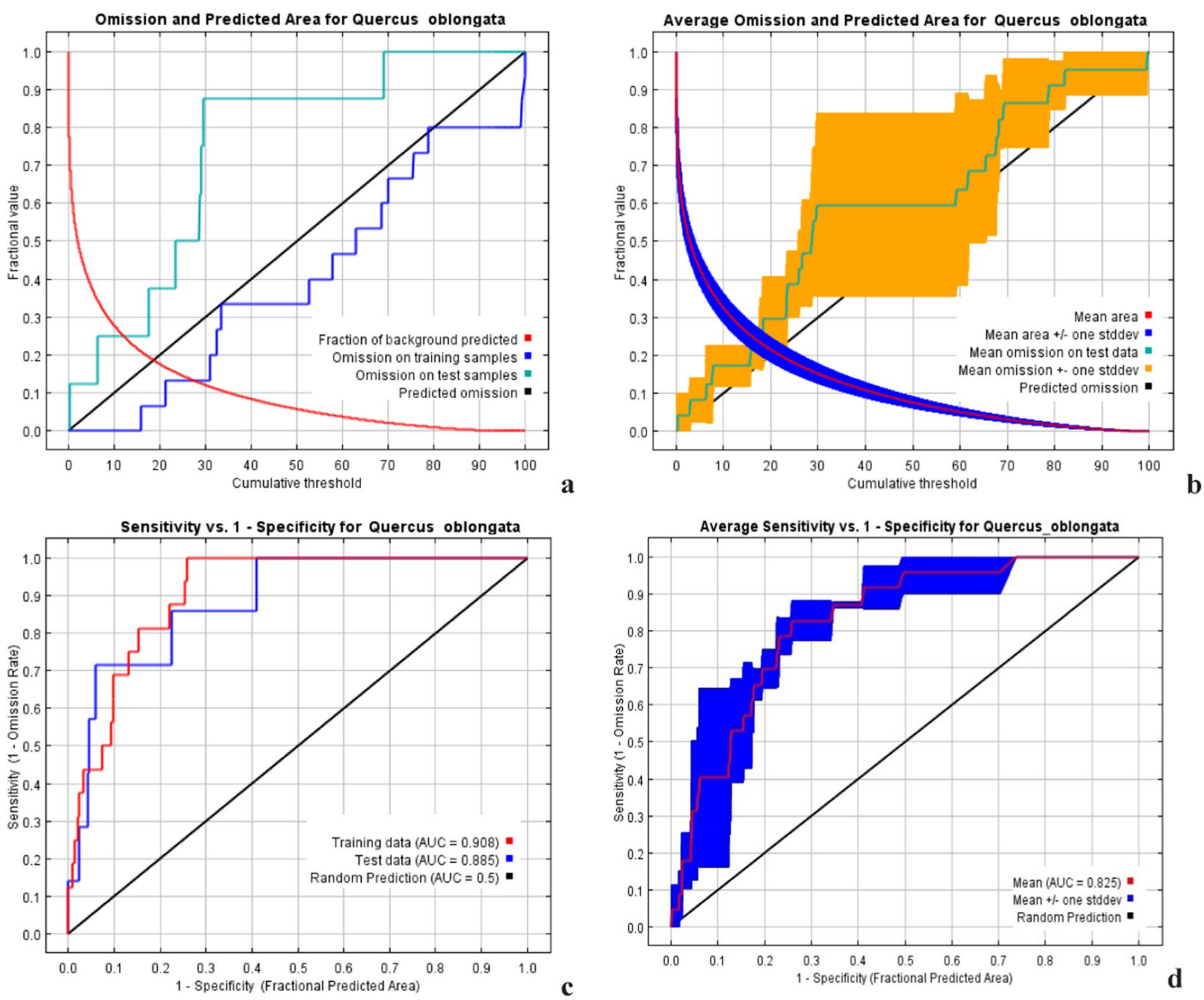


Fig. 9 **a** Omission rate and predicted area as a function of cumulative threshold; **b** Test omission rate and predicted area as a function of cumulative threshold averaged over the replicate runs; Model performance; **c** ROC curve displays sensitivity and 1-specificity with AUC for training (0.908) and test (0.885); and **d** Average test AUC for replicated runs 0.825

$r=0.7482$, $n=14$, $p\leq0.05$). The species richness showed negative correlation along the altitude ($R^2=0.1761$, $r=-0.4196$, $n=14$, $p\leq0.05$), that revealed decreased species richness with the increasing altitude attributed to severe climatic conditions at the higher elevations making unfavorable for the survival of various species. Negative correlation observed between seedlings density and altitude ($R^2=0.4204$, $r=-0.6483$, $n=14$, $p\leq0.05$) and density of tress with density of shrubs ($R^2=0.1116$, $r=0.3340$, $n=14$, $p\leq0.05$) (Fig. 12a–h).

4 Discussion

Natural resources are essential to human survival, and the northwestern Himalayas are provided with a wide variety of floristic diversity that is significant from an ecological and economic standpoint, including Ban oak. Ban oak's natural populations are being depleted due to an increase in demand and the unsustainable exploitation for foraging. Structural diversity of forest

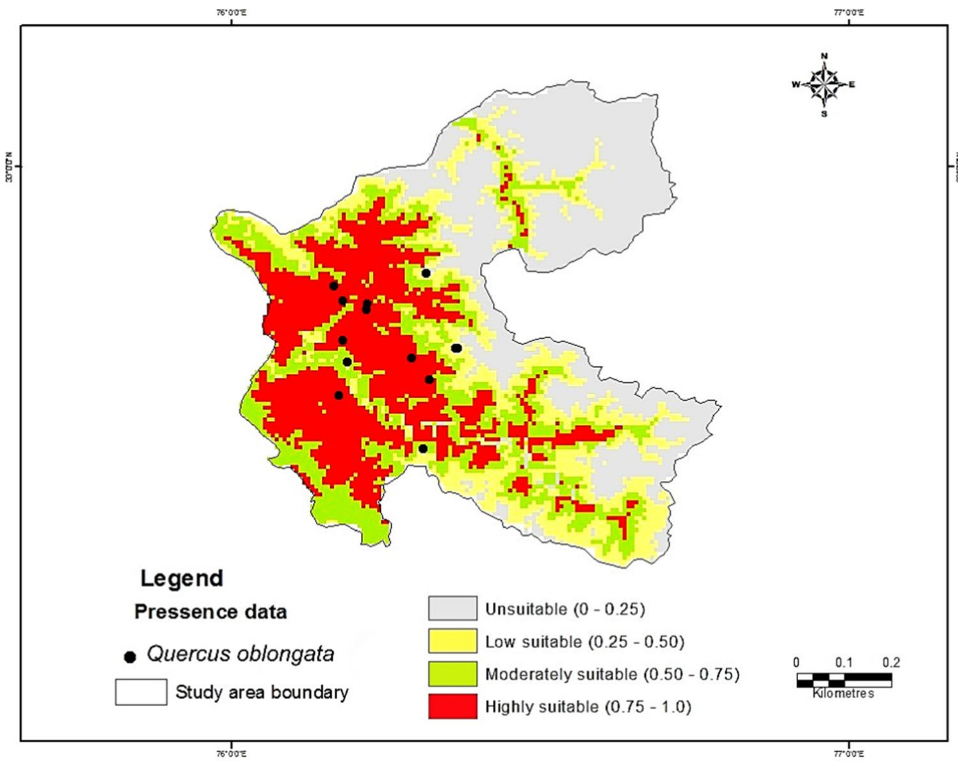


Fig. 10 Suitable probability distribution map of *Q. oblongata* in Chamba district

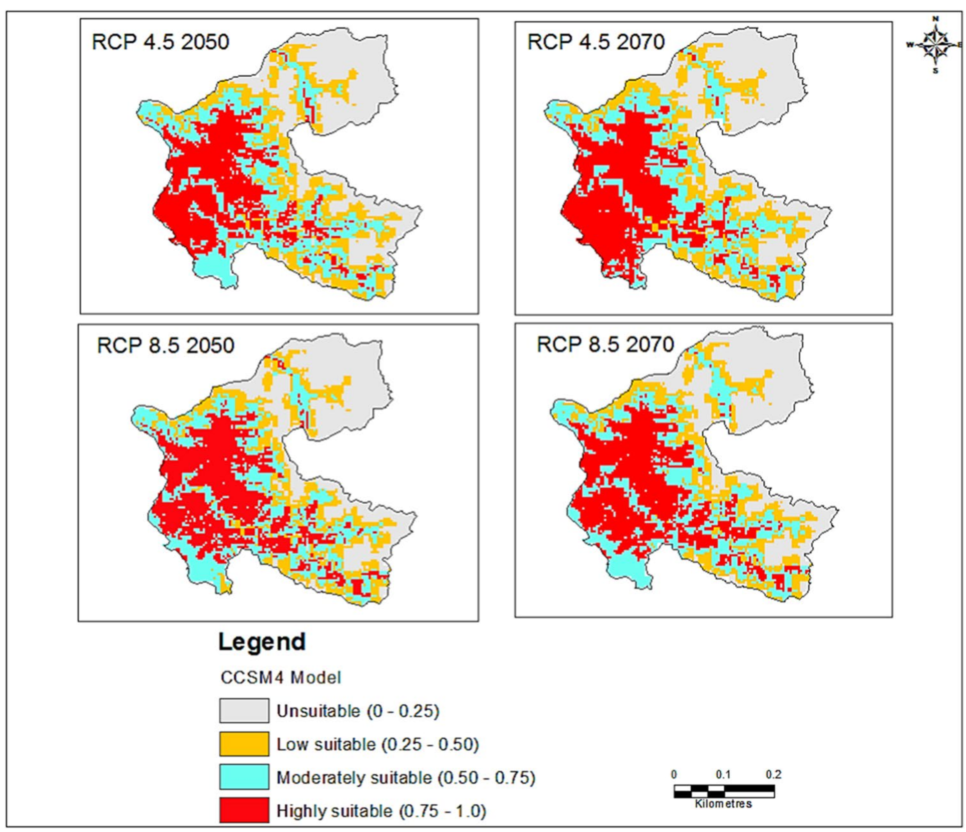


Fig. 11 Potential areas of *Q. oblongata*'s occurrence and distribution in Chamba district in future IPCC RCPs (Representative Concentration Pathways) for the years 2050 and 2070

Table 4 Values of biomass estimation in Chamba district, northwestern Himalaya

Populations	1 (Mg ha^{-1})	2 (Mg ha^{-1})	3 (Mg ha^{-1})	4 (Mg ha^{-1})	5 (Mg ha^{-1})	6 (Mg ha^{-1})	7 (Mg ha^{-1})	8 (Mg ha^{-1})
Dumas-Tissa	111.05 ± 18.46	110.80	32.21 ± 5.35	32.13	143.26 ± 23.81	142.94	71.63 ± 11.91	71.47
Chaned	20.16 ± 0.03	19.51	05.85 ± 0.01	05.66	26.00 ± 0.04	25.16	13.00 ± 0.02	12.58
Banikhet	164.94 ± 11.61	43.86	47.83 ± 3.37	12.72	212.78 ± 14.97	56.58	106.39 ± 7.49	28.29
Mankot	15.18 ± 0.34	10.52	04.40 ± 0.10	03.05	19.58 ± 0.44	13.57	09.79 ± 0.22	06.79
Khajjiar-I	24.74 ± 2.36	15.17	07.18 ± 0.68	04.40	31.92 ± 3.04	19.57	15.96 ± 1.52	09.79
Khajjiar-II	65.38 ± 13.26	65.06	18.96 ± 3.85	18.87	84.34 ± 17.10	83.93	42.17 ± 8.55	41.97
Bhujnoi-Gate	43.18 ± 4.61	33.18	19.62 ± 1.34	10.13	76.63 ± 8.31	43.79	42.68 ± 7.81	42.61
Jot	30.79 ± 4.52	23.67	08.93 ± 1.31	06.86	39.72 ± 5.84	30.54	19.86 ± 2.92	15.27
Hatli-Dramman	13.01 ± 0.22	10.80	03.77 ± 0.06	03.13	16.79 ± 0.28	13.93	08.39 ± 0.14	06.97
KKWS-I	84.67 ± 9.01	76.91	61.53 ± 1.02	52.84	146.2 ± 15.63	129.75	73.10 ± 9.02	64.87
KKWS-II	62.73 ± 3.12	58.19	30.87 ± 1.25	19.67	93.60 ± 12.25	77.86	46.80 ± 6.88	38.93
KKWS-III	72.56 ± 4.25	64.33	41.61 ± 2.01	37.65	114.17 ± 13.56	101.98	57.08 ± 4.52	50.99
KKWS-IV	82.48 ± 3.58	76.63	48.52 ± 2.52	38.52	131.00 ± 10.25	115.15	65.50 ± 3.61	57.58
KKWS-V	80.15 ± 2.85	78.63	42.37 ± 1.36	40.88	122.52 ± 9.21	119.51	61.23 ± 3.05	59.78

KKWS Kalatop Khajjiar Wildlife Sanctuary; 1 = Total above ground biomass density; 2 = Above ground biomass density of *Quercus oblongata*; 3 = Total below ground biomass density; 4 = Below ground biomass density of *Quercus oblongata*; 5 = Total biomass density; 6 = Biomass density of *Quercus oblongata*; 7 = Total carbon density and 8 = Carbon density of *Quercus oblongata*

vegetation, species composition and distribution patterns are the main focus of ecological studies (Rana et al. 2021). Conducting appropriate ecological research and raising public awareness are the need to protect the biodiversity components of any biogeographic area and are essential for the conservation of plant species and for understanding forest dynamics (Barik and Adhikari 2012; Polak and Saltz 2011). One of the most significant indicators that can be used to assess ecosystems at various scales is the floral variety and species composition of a forest community (Rana et al. 2021). Numerous indicators, including the Shannon index, species density, species diversity, and concentration of dominance, may be used to anticipate the complexity of plant communities and comprehend the dynamics of a forest (Rana et al. 2021). Ecological studies provide detailed information on the homeostatic capacity of any forest ecosystems to unforeseen environmental changes (Christopher 2020).

The northwestern Himalaya including Chamba district of Himachal Pradesh is blessed with diverse floristic diversity of ecological and economical importance including Ban oak. Decent species variety within the same forest type is shown by the presence of 188 plants at the floor of ban oak forests in the analyzed populations. This might be attributed to the distinctive geography of the northwestern Himalayas and to environmental factors that are conducive to the species' development (Rana et al. 2020). In comparison to past studies done in the Himalayan zones, the number of species found in the Chamba is lower. Kais Wildlife Sanctuary recorded 607 vascular plant species in total (Lal and Samant 2019), Manali Wildlife Sanctuary reported 637 vascular plant species (Rana and Samant 2009), and Cold Desert Biosphere Reserve reported 354 medicinal plant species (Singh 2007). The threat on ban oak forests is evident from this outcome. The presence of a large number of species in the older research may be attributable to protected regions, where there is less anthropogenic activity.

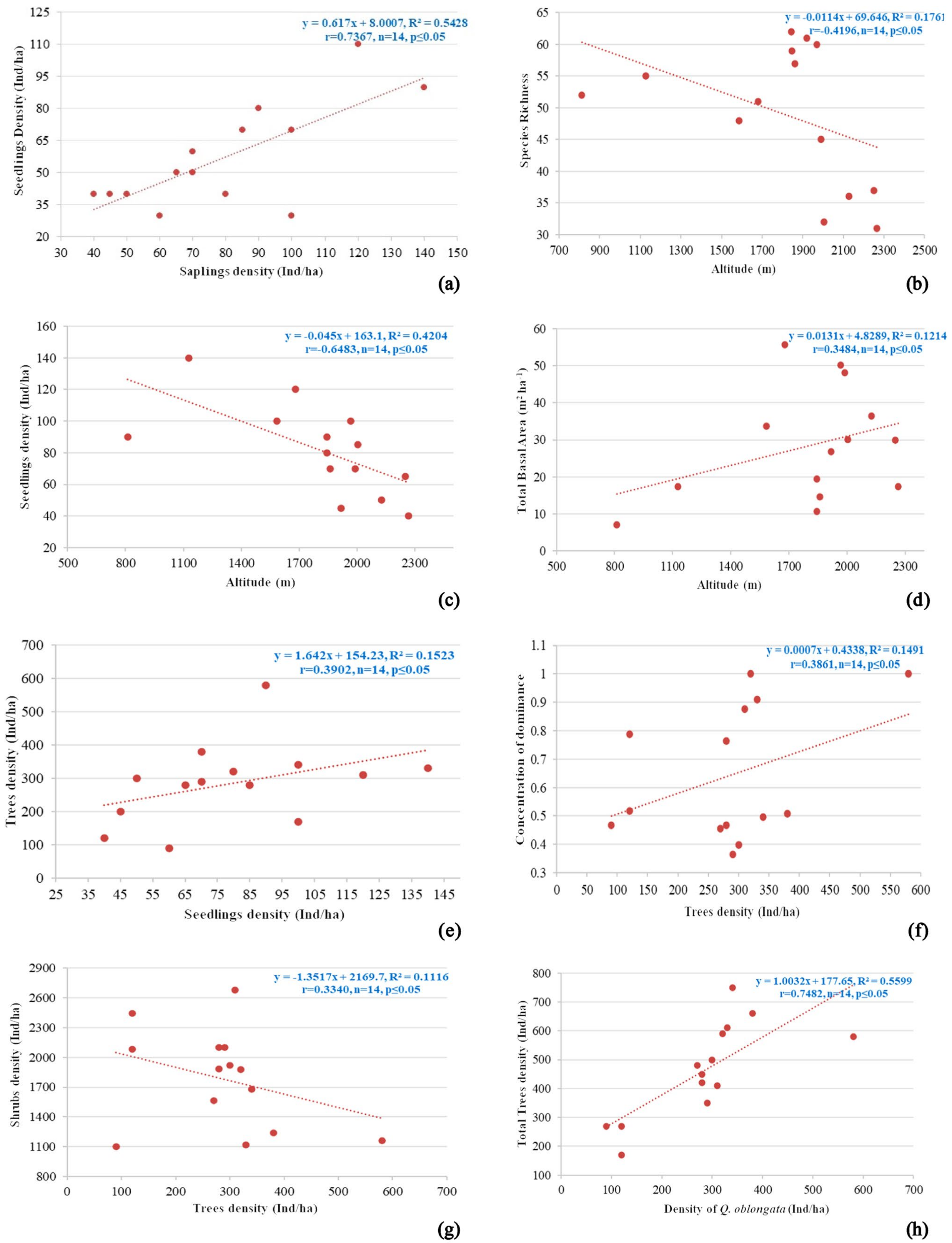
Species diversity is defined as the number of different species present in an ecosystem, i.e., species richness and relative abundance of each of those species. Because the variation across various communities is influenced by the variety of both the microclimate and the macroclimate, long-term variables like community stability and evolutionary time influence the species diversity (Verma et al. 2004). The study site with more species variation tends to be more stable and resilient than the sites which are dominated by monotypic communities. According to previous findings like Lal and Samant 2019 (*H*': 0.27–2.17) and Rana et al. 2021 (*H*': 1.40–2.10), the reported range of tree diversity was lower in the present study (0.07–0.49). While for the shrubs it is also reported low (0.58–2.16) comparing other studies (Rana et al. 2021; Rana and Samant 2009; Pant and Samant 2012). This result illustrates the pressure on ban oak forests and urge conservation needs. In case of herbs, species diversity (2.21–4.17) was comparable than the earlier reported values (Samant et al. 2002 (2.74–4.13); Lal and Samant 2019 (2.88–4.26)). Low protection and conservation efforts, unsustainable harvesting, significant human activity, and a lack of adequate soil cover are further factors that contribute to the area's low species diversity.

The study was conducted only in the accessible habitats having < 65° Slope; thus, some sites having accessibility issues. Only representative sites were selected from the district which is mainly dominated by ban oak. The maximum numbers of populations were represented by shady and moist habitat indicating that these habitats form the best platform for the overall development of the species. The high values of basal area for shady moist habitat indicated the availability of sufficient nutrients and the favorable environmental conditions for development. This is due to the sparse distribution of individuals and less competition for nutrients. Distribution of *Q. oblongata* is mostly found in south aspects which is similar to the trends that are found in other parts of the IHR (Devi et al. 2019; Lal and Samant 2019; Barman et al. 2021) and probably due to the favorable ecological landscapes. The study reveals that the maximum density of *Q. oblongata* is found at an elevation of 2000 m ± 500 m amsl and clearly states the growth preference of Ban oak along an altitudinal gradient and this growth preference was also recorded by Dhyani et al (2020). These aspects, elevation and habitats are responsible for proper establishment of the species.

Q. oblongata is a dominant species of a highly diverse forest ecosystem with its associate tree species viz., *Rhododendron arboreum, Lyonia ovalifolia, Pyrus pashia, Quercus floribunda, Aesculus indica* and *Neolitsea pallens* (Dhyani et al. 2020). The rich diversity of the herbs, shrubs, pteridophytes, and epiphytes is also noticeable in Ban oak forests. The highest *H*' of trees on moist habitat and southern aspect, along with the highest *H*' of shrubs in moist slopes and southwestern aspect and the highest *H*' of herbs in shady habitat and west and southwest aspects, revealed the suitability of these topographic gradients for *Q. oblongata* in the studied populations, hence require priority attention for conservation. An examination of the dispersion pattern revealed that, in the case of trees, most species exhibited uniform distribution, with a few species exhibiting random distribution (Singh et al. 2016a, 2016b). In general, it has been observed that density, basal area, total basal area, species richness, species diversity and concentration of dominance varied from habitat to habitat and aspect to aspect. The regeneration status of a tree species is determined by the presence of seedlings and saplings in the forests (Joshi and Samant 2004, 2014). The results of correlations are comparable with the previous studies conducted in the other regions of the Western Himalaya (Sharma and Samant 2013).

The capacity for regeneration of a species that make the forest, both spatially and temporally, determines the forests wealth. Old trees die and are continuously replaced by new ones during the regeneration of a forest (Malik and Bhatt 2016). The structure of a forest vegetation is categorized by the presence of sufficient number of seedlings, saplings, and young trees. Adequate number of seedlings and saplings depicts "good" regeneration trend, inadequate number of seedlings and saplings indicate "poor" regeneration, and complete absence of seedlings and saplings indicates "no" regeneration (Singh et al. 2016a, b). In the present study, the occurrence of the moderate number of *Q. oblongata* individuals under sapling classes and young tree classes shows that the populations of this species will continue to dominate in the future also. However, frequent monitoring of the populations will help in understanding the dynamics of the populations of *Q. oblongata* in the context of anthropogenic factors and climate change (Thadani and Ashton 1995). The poor recruitment and establishment of seedlings of the species in the recorded populations may be due to high tree canopy coverage and lack of microhabitat, high litter accumulation and low light availability affecting the seed germination of *Q. oblongata*. Total seedlings density ranged from 80 to 370 Ind ha^{-1} and total saplings density ranged from 30 to 160 Ind ha^{-1} and is comparable with the previous studies (Pant and Samant 2012; Singh et al. 2021; Paul et al. 2019). Discontinuous distribution pattern of *Q. oblongata* seedlings was observed along with increasing altitude and changing aspects. The maximum studied population was recorded with low seedling density. The gap in the distribution of *Q. oblongata* seedlings might be due to high heterogeneity. Other factors responsible for the discontinuous recruitment of seedlings may be high canopy cover and aspect. Absence of seedlings density in the southwest and northeast aspects also supports the fact that aspect plays a crucial role in species distribution (Samant et al. 2002).

The edaphic factors, moisture content and nutrients are required for the survival of most of the species. Spatial variations in soil properties in forests are mainly due to the rooting pattern and litter accumulation. Soil moisture and temperature are limiting and controlling factors for the significant variation in topographical characters and vegetation pattern. Increase in moisture content with elevation might be due to decrease in temperature and increase in tree canopy cover and availability of water sources (Dasila et al. 2020). It was assumed that soil moisture availability affects the regeneration of species in ban oak forests (Dhyani et al. 2020). However, inadequate soil moisture might be responsible for seed germination and recruitment of seedlings and saplings in the studied populations. Seedlings are more sensitive to moisture deficiency than deep-rooted mature plants, which might be attributed to slow initial growth. Thus, lack of suitable microhabitat for seed germination and adverse climatic conditions and anthropogenic pressures might be responsible for lower recruitment and establishment of seedlings in the studied populations. In the plot clustering could be clearly observed showing close association of habitats within the cluster and the sharing of same. The close association of some habitats suggests that these species are affected in nearly the same way and concentration by the available biotic and abiotic factors, and as a result, their importance values are nearly identical. In addition, altitude influenced


y = 0.617x + 8.0007, R² = 0.5428
r=0.7367, n=14, p≤0.05
Seedlings Density (Ind/ha)
Saplings density (Ind/ha)
(a)
y = -0.0114x + 69.646, R² = 0.1761
r=-0.4196, n=14, p≤0.05
Species Richness
Altitude (m)
(b)
y = -0.045x + 163.1, R² = 0.4204
r=-0.6483, n=14, p≤0.05
Seedlings density (Ind/ha)
Altitude (m)
(c)
y = 0.0131x + 4.8289, R² = 0.1214
r=0.3484, n=14, p≤0.05
Total Basal Area (m² ha⁻¹)
Altitude (m)
(d)
y = 1.642x + 154.23, R² = 0.1523
r=0.3902, n=14, p≤0.05
Trees density (Ind/ha)
Seedlings density (Ind/ha)
(e)
y = 0.0007x + 0.4338, R² = 0.1491
r=0.3861, n=14, p≤0.05
Concentration of dominance
Trees density (Ind/ha)
(f)
y = -1.3517x + 2169.7, R² = 0.1116
r=0.3340, n=14, p≤0.05
Shrubs density (Ind/ha)
Trees density (Ind/ha)
(g)
y = 1.0032x + 177.65, R² = 0.5599
r=0.7482, n=14, p≤0.05
Total Trees density (Ind/ha)
Density of Q. oblongata (Ind/ha)
(h)

◂**Fig. 12** **a** Correlation between saplings density and seedlings density; **b** Correlation between species richness and altitude; **c** correlation between seedlings density and altitude; **d** correlation between total basal area and altitude; **e** correlation between trees density and seedlingsdensity; **f** correlation between trees density and concentration of dominance; **g** correlation between trees density and shrubs density and **h** correlation between total trees density and density of *Q. oblongata*

the dispersion of these species in the study area. Populations such as Jot, KKWS-IV, Dumas-Tissa and KKWS-V did not share the relation/habitats/niches with any individually and uniquely in the study area, they differed from other populations. High tree density and dense canopy would provide sufficient humus and soil moisture, which is required for seed germination. However, the establishment and survival of seedlings and saplings would depend on other biotic and abiotic factors such as weather conditions, anthropogenic activities, grazing, richness, and ecosystem properties (Kumar and Ram 2005). The availability of nitrogen would depend, to a large extent, on the quantity and properties of organic matter (De Hann 1977). Therefore, the high amount of organic matter in the forest might also be the reason for richness of nitrogen content (Singh et al. 2021).

The prediction of habitat shifts using ENM/SDM tools is essential for orienting the human-assisted efforts in recruitment and regeneration of the slow growth of ban oak with appropriate Silviculture efforts, especially in the degraded oak forest patches (Dhyani et al. 2020). For habitat suitability modelling, MaxEnt Model is very suitable, and the overall accuracy of the model is high. Maxent was efficiently used to predict the current distribution and changes in the future distribution patterns in response to the climate change of ecologically and economically important ban oak. Multi-collinearity test was performed to choose the variables most appropriately, which helps in modelling, eco-distribution mapping and prediction of the species across the geographical space (Supplementary Table 4). An AUC value of 0.908 is closer to 1.0 which indicates better model performance. The AUC test (0.908) values were comparable to the values earlier reported for *Drepanostachyum falcatum* (0.978) in Himachal Pradesh (Samant and Lal 2015); *Carpinus viminea* (0.954) and *Corylus jacquemontii* (0.938) in Himachal Pradesh (Paul et al. 2018, 2019), *Quercus oblongata* (0.876) in central Himalaya (Dhyani et al. 2020), *Quercus semecarpifolia* (0.902) and *Betula utilis* (0.912) in Great Himalayan National Park (Singh et al. 2021), *Taxus contorta* (0.905) in Himachal Pradesh (Chauhan et al. 2022). It is important to note that AUC values tend to be lower for species that have broad distribution scope. The highly suitable, suitable, and moderately suitable classes can be considered for the reintroduction (*in situ* conservation) of the species (Singh et al. 2021). The areas being identified as having high suitability (i.e., highly suitable and suitable areas) showed high densities of trees, saplings, and seedlings. The potential habitat distribution map can help in categorizing the potential distribution regions, especially in the highly suitable and suitable areas. This suggests a need for development of conventional propagation protocols for mass multiplication, establishment, and maintenance of nurseries for quality planting material and dissemination to the local inhabitants and the Forest Department for plantation in the highly suitable, suitable, and moderately suitable areas of district Chamba.

Forests act as net carbon sinks and are one of the main sources of fixing of atmospheric carbon. The adverse climatic conditions along the altitudinal gradients considerably affect the growth and development of trees, therefore further carbon accumulation in temperate forests, and lower biomass at high altitudes could be due to the cold temperature. Studied populations were mainly dominated by moist temperate oak forest and play a significant role in carbon sequestration as tree biomass is one of the main carbon sinks. Nutrient supply become more limiting factor to the plants at higher altitudes thereby limiting forest productivity and biomass accumulation. The mature forest ecosystem accounts for higher carbon stock than young and juvenile forests. Maximum carbon sink was observed in Kalatop Khajjiar Wildlife Sanctuary and adjoin studied populations also indicated to promotion of the carbon management through afforestation in northwestern Himalaya. In the present study, above ground biomass density for *Q. oblongata* was ranged from 10.52 to 110.80 Mg ha^{-1} and below ground biomass density ranged from 3.05 to 52.84 Mg ha^{-1}. The values of AGB are comparatively very low and BGB more or less comparable with the study reported by Bisht et al. (2022) in central Himalaya for ban oak (AGB: 204.6–497.2 Mg ha^{-1}; BGB: 58.4–130.20 Mg ha^{-1}).

The protection of forest biodiversity remains a major challenge in the management of forest resources in the era of climate induced vulnerable ecosystems. Botanical and ecological data can provide basic information about the many alterations in any forest vegetation and biodiversity over the period of time. Main implications for the conservation are inadequate knowledge of forest botany among the foresters and other professionals is leading to the plantations of wrong species causing unorganized management of the forest areas (Rana et al. 2021), lack of financial assistance and accessibility, less awareness among the mountain natives, lack of infrastructure and monitoring, and finally lack of implementation of official orders in ground levels that ultimately increase less conservation. Vegetation ecology investigates the species composition and their sociological interaction in communities (Mueller and Ellenberg 1974). Biodiversity is mostly considered for human sustenance, secure economy and societal benefits. Biodiversity of oak forests has been continuously declining throughout the northwestern Himalaya during the past decades, despite its recognized importance to sustainable livelihood, human well-being, ecosystem functioning, services, resistance and resilience under climate change. The best approach to protect and conserve the existing mixed broadleaved oak forests, which is a life support to millions of rural inhabitants in the northwestern Himalaya, is by supporting natural course of regeneration, and conserving and reducing pressure on soil seed bank, in the light of climate vulnerabilities (Dhyani et al. 2020). This is where local communities will have a very important role to play in conservation and protection of Ban oak forests.

Extraction of Ban oak from its natural ecosystem is growing at an alarming rate due to its multiple purpose and many ecosystem services which ultimately creates huge pressure on natural regeneration in the wild (Rawal et al. 2012). This study provides comprehensive information on physical characteristics, richness, density, total basal area, species diversity, concentration of dominance, regeneration, pattern along with the details of physico-chemical properties of soil, size class distribution, and habitat suitability modelling and population ecology of *Q. oblongata*. The study would not only help in eco-restoration of the habitats, but also in recovering the species population and improving its *in situ* conservation (Paul et al. 2018). However, the changing environmental conditions, especially climate change coupled with continued anthropogenic pressure, may lead to reduced populations of *Q. oblongata* and replacement by other species with no or very low economic value (Samant et al. 2006).

If properly used, the phytosociological research may be very useful and important for managing the biodiversity in the area. The vegetation indices may be used to forecast forest ecosystem structure and comprehend vegetation dynamics. Measures that are specific to communities and habitats are crucial for the preservation of biological variety. Therefore, there is an urgent need to create awareness among the native communities, forest department, NGOs, and other stakeholders on status, soil requirement, economic values and conservation of the species. Frequent monitoring of the natural habitats and development of conventional propagation protocols for mass multiplication and establishment of seedlings in *in situ* and *ex situ* conditions are suggested for conservation and sustainable utilization of the species. This would serve the local communities for prosperity in future.

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Author contributions All authors contributed to the study conception. Material preparation, research design, field data collection, floristic data and statistical analysis and draft manuscript writing including results and discussion were performed by TB and also answered the reviewer's comments. SSS contributed to the identification of flora, overall coordination, guiding and management during the research period and review and editing of the draft manuscript. LMT contributed to the preparation of the manuscript. Future projection Maps were prepared by NK. PCA was done by AS. Study area map and editing was done by SP. SL contributed to editing of the manuscript. All authors read and approved the final manuscript.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Adhikari D, Barik SK, Upadhaya K (2012) Habitat distribution modelling for reintroduction of *Ilex khasiana* Purk, a critically endangered tree species of northeastern India. Ecol Eng 40:37–43. https://doi.org/10.1016/j.ecoleng.2011.12.004

Adhikari D, Reshi Z, Datta BK, Samant SS, Chettri A, Upadhaya K, Shah MA, Singh PP, Tiwary R, Majumdar K, Pradhan A (2018) Inventory and characterization of new populations through ecological niche modelling improve threat assessment. Curr Sci 114:519–531. https://doi.org/10.18520/cs%2Fv114%2Fi03%2F519-531

Allen SE, Grimshaw HM, Parkinson JA, Quarmby C (1974) Chemical analysis of ecological materials. Blackwell Scientific Publications, UK

Austin MP (1977) Use of ordination and other multivariate descriptive methods to study succession. Vegetat 35:165–175. https://doi.org/10.1007/BF02097067

Barbosa ILBD, Oliveira HR, Terribile LC and Diniz-Filho JAF (2019). Geographical distribution of *Stryphnodendron adstringens* Mart. Coville (Fabaceae): modeling effects of climate change on past, present and future. Rev Bras Bot, 42:53–61

Barik S, Adhikari D (2012) Predicting geographic distribution of an invasive species *Chromolaena odorata* L. King and H.E. Robins in Indian subcontinent under climate change scenarios. In: Bhatt JR, Singh JS, Singh SP, Tripathi RS, Kohli RK (eds) Invasive Alien Plants: an ecological appraisal for the Indian subcontinent. CAB International., CPI Group (UK) Ltd, Croydon, UK, 77–88. https://doi.org/10.1079/9781845939076.0077

Barman T, Samant SS, Jyoti SA (2021) Structural diversity and regeneration pattern of forest communities in Parbati Valley, north western Himalaya, India: implications for conservation. Ind J Ecol 48:332–348

Birch EL (2014) A review of "climate change 2014: impacts, adaptation, and vulnerability" and "climate change 2014: mitigation of climate change." J Am Plann Assoc 80:184–185

Bisht S, Bargali SS, Bargali K, Rawat GS, Rawat YS, Fartyal A (2022) Influence of anthropogenic activities on forest carbon stocks: a case study from Gori Valley, Western Himalaya. Sustain 14:16918

Chakraborty A, Saha S, Sachdeva K, Joshi PK (2018) Vulnerability of forests in the Himalayan region to climate change impacts and anthropogenic disturbances: a systematic review. Reg Environ Chang 18:1783–1799. https://doi.org/10.1007/s10113-018-1309-7

Chambers JQ, dos Santos J, Ribeiro RJ, Higuchi N (2001) Tree damage, allometric relationships, and above-ground net primary production in central Amazon forest. For Ecol Manage 152:73–84

Champion HG, Seth SK (1968) A revised survey of the forest types of India. Manager of publications

Chaturvedi RK, Gopalakrishnan R, Jayaraman M, Bala G, Joshi NV, Sukumar R, Ravindranath NH (2011) Impact of climate change on Indian forests: a dynamic vegetation modeling approach. Mitig Adapt Strateg Glob Chang 16:119–142. https://doi.org/10.1007/s11027-010-9257-7

Chauhan S, Ghoshal S, Kanwal KS, Sharma V, Ravikanth G (2022) Ecological niche modelling for predicting the habitat suitability of endangered tree species *Taxus contorta* Griff. in Himachal Pradesh (Western Himalayas, India). Trop Ecol 63:300–313

Chettri A, Pradhan A, Sharma G, Pradhan BK (2018) Habitat distribution modelling of seabuckthorn (*Hippophae salicifolia* D. Don) in Sikkim, Eastern Himalaya. India Ind J Ecol 2:266–269

Condit R, Sukumar R, Hubbell SP, Foster RB (1998) Predicting population trends from size distributions: a direct test in a tropical tree community. Am Nat 152:495–509. https://doi.org/10.1086/286186

Curtis J, McIntosh R (1950) The interrelations of certain analytic and synthetic Phytosociological characters. Ecology 31:434–455. https://doi.org/10.2307/1931497

Dale VH, Joyce LA, McNulty S, Neilson RP, Ayres MP, Flannigan MD, Hanson PJ, Irland LC, Lugo AE, Peterson CJ, Simberloff D (2001) Climate change and forest disturbances: climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. Bioscience 51:723–734. https://doi.org/10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2

Dasila K, Pandey A, Samant SS, Pande V (2020) Endophytes associated with Himalayan silver birch (Betula utilis D. Don) roots in relation to season and soil parameters. Appl Soil Ecol 149:103513. https://doi.org/10.1016/j.apsoil.2020.103513

Dawson TP, Jackson ST, House JI, Prentice IC, Mace GM (2011) Beyond predictions: biodiversity conservation in a changing climate. Science 332:53–58. https://doi.org/10.1126/science.1200303

De Haan S (1977) Humus, its formation, its relation with the mineral part of the soil, and its significance for soil productivity. Soil Org Mat Stud 1:21–30

Devi RM, Patasaraiya MK, Sinha B, Saran S, Dimri AP, Jaiswal R (2018) Understanding the linkages between climate change and forest. Curr Sci 114:987–996

Devi K, Samant SS, Puri S, Lal M (2019) Diversity, structure and regeneration pattern of tree communities in Kanawar Wildlife Sanctuary of Himachal Pradesh, North Western Himalaya, India. Ind J Ecol 46:94–103

Dhar U, Rawal RS, Samant SS (1997) Structural diversity and representativeness of forest vegetation in a protected area of Kumaun Himalaya, India: implications for conservation. Biodivers Conserv 6:1045–1062

Dhyani S, Kadaverugu R, Pujari P (2020) Predicting impacts of climate variability on Banj oak (*Quercus leucotrichophora* A. Camus) forests: understanding future implications for Central Himalayas. Reg Environ Change 20:1–13. https://doi.org/10.1007/s10113-020-01696-5

Dormann FC, McPherson CM, Araujo JB, Bivand M, Bolliger R, Carl J, Davies GG, Hirzel R, Jetz A, Daniel Kissling W, Kuhn W, Ohlemuller I, Peres-Neto RR, Reineking P, Schroder B, Schurr F, Wilson R (2007) Methods to account for spatial autocorrelation in the analysis of species distributional data: a review. Ecography 30:609–628. https://doi.org/10.1111/j.2007.0906-7590.05171.x

Elith J, Kearney M, Phillips S (2010) The art of modelling range-shifting species. Methods Ecol Evol 1:330–342. https://doi.org/10.1111/j.2041-210X.2010.00036.x

Ellison D, Morris CE, Locatelli B, Sheil D, Cohen J, Murdiyarso D, Gutierrez V, Van Noordwijk M, Creed IF, Pokorny J, Gaveau D (2017) Trees, forests and water: cool insights for a hot world. Glob Environ Change 43:51–61. https://doi.org/10.1016/j.gloenvcha.2017.01.002

Fielding AH, Bell JF (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. Environ Conserve 24:38–49. https://doi.org/10.1017/S0376892997000088

Greig-Smith P (1957) Quantitative plant ecology. Academic Press, New York

Han WX, Fang JY, Reich PB, Ian Woodward F, Wang ZH (2011) Biogeography and variability of eleven mineral elements in plant leaves across gradients of climate, soil and plant functional type in China. Ecol Lett 14:788–796. https://doi.org/10.1111/j.1461-0248.2011.01641.x

Hijmans RJ, Phillips S, Leathwick J, Elith J (2017) dismo: Species distribution modeling. R Package Version 1:1–1

Jackson ML (1958) Soil chemical analysis. Prentice-Hall, London

Joshi AK, Juyal D (2017) Traditional and ethnobotanical uses of *Quercus leucotrichophora* a. Camus (*Quercus oblongata* D. Don) in Kumaun and Garhwal regions of Uttarakhand, India: a review. Int J Herb Med 5:06–08

Joshi HC, Samant SS (2004) Assessment of forest vegetation and conservation priorities of communities in part of Nanda Devi biosphere reserve, West Himalaya. Part I. Int J Sust Dev World Ecol 11:326–336. https://doi.org/10.1080/13504500409469835

Joshi HC, Samant SS (2014) Change in structural and compositional diversity with altitude: a study from Nanda Devi Biosphere Reserve (NDBR), West Himalaya, India. Ind J for 37:121–136

Kalakoti BS, Pangtey YS, Saxena AK (1986) Quantitative analysis of high altitude vegetation of Kumaun Himalaya. J Ind Bot Soc 65:384–396

Kardol P, Wardle DA (2010) How understanding aboveground–belowground linkages can assist restoration ecology. Trends Ecol Evol 25:670–679. https://doi.org/10.1016/j.tree.2010.09.001

Keenan RJ, Reams GA, Achard F, de Freitas JV, Grainger A, Lindquist E (2015) Dynamics of global forest area: results from the FAO global forest resources assessment 2015. For Ecol Manage 352:9–20. https://doi.org/10.1016/j.foreco.2015.06.014

Kersaw KA (1973) Quantitative and dynamic plant ecology, 2nd edn. Edward Arnold Limited, London

Kumar A, Ram J (2005) Anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, Central Himalaya. Biodivers Conserv 14:309–331. https://doi.org/10.1007/s10531-004-5047-4

Kumar M, Singh H, Pandey R, Singh MP, Ravindranath NH, Kalra N (2019) Assessing vulnerability of forest ecosystem in the Indian Western Himalayan region using trends of net primary productivity. Biodivers Conserv 28:2163–2182

Kuzovkina YA, Volk TA (2009) The characterization of willow (*Salix* L.) varieties for use in ecological engineering applications: co-ordination of structure, function and autecology. Ecol Eng 35:1178–1189. https://doi.org/10.1016/j.ecoleng.2009.03.010

Lal M, Samant SS (2015) Diversity, distribution, ecological niche modeling and economic importance of bamboo species in North Western and Western Himalaya. In hill bamboos: an important resource for improving rural livelihoods. In: Tewari VP, Verma RK, Goraya GS (eds), Hill Bamboos: an important resource for improving rural livelihoods. Himalayan Forest Research Institute, Shimla, 01–20.

Lal M, Samant SS (2017) Niche modelling: an approach to predict habitats for conservation of *Hippophae* species in Trans and North Western Indian Himalaya. Int J Sci Nat 8:437–446

Lal M, Samant SS (2019) Compositional and structural diversity of forest vegetation in Kais Wildlife Sanctuary, north western Himalaya: conservation implications. J Biodivers 10:1–14. https://doi.org/10.31901/24566543.2019/10.1-2.083

Lal M, Samant SS, Kumar R, Sharma L, Paul S, Dutt S, Negi D, Devi K (2020) Population ecology and niche modelling of endangered *Arnebia euchroma* in Himachal Pradesh, India: an approach for conservation. Med Plants - Int J Phytomed Relat Ind 12:90–104

Laurance WF, Ferreira LV, Rankin-De Merona JM, Hutchings RW (1998) Influence of plot shape on estimates of tree diversity and community composition in central Amazonia. Biotropica 30:662–665. https://doi.org/10.1111/j.1744-7429.1998.tb00106.x

Li G, Du S, Wen Z (2016) Mapping the climatic suitable habitat of oriental arborvitae (*Platycladus orientalis*) for introduction and cultivation at a global scale. Sci Rep 6:01–09. https://doi.org/10.1038/srep30009

Malik ZA, Bhatt AB (2016) Regeneration status of tree species and survival of their seedlings in Kedarnath Wildlife Sanctuary and its adjoining areas in Western Himalaya, India. Trop Ecol 57:677–690

Marchese C (2015) Biodiversity hotspots: a shortcut for a more complicated concept. Glob Ecol Conserv 3:297–309. https://doi.org/10.1016/j.gecco.2014.12.008

Mir AH, Tyub S, Kamili AN (2020) Ecology, distribution mapping and conservation implications of four critically endangered endemic plants of Kashmir Himalaya. Saudi J Biol Sci 27:2380–2389. https://doi.org/10.1016/j.sjbs.2020.05.006

Mueller-Dombois D, Ellenberge H (1974) Aims and methods of vegetation ecology. Willey, New York.https://doi.org/10.2307/213332

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Government Print Office, Washington, USA

Oluyinka Christopher A (2020) Comparative analyses of diversity and similarity indices of west bank forest and block a forest of the International Institute of Tropical Agriculture (IITA) Ibadan, Oyo State, Nigeria. Int J For Res. https://doi.org/10.1155/2020/4865845

Pant S, Samant SS (2008) Population ecology of the endangered Himalayan Yew in Khokhan Wildlife sanctuary of North Western Himalaya for conservation management. J Mt Sci 5:257–264. https://doi.org/10.1007/s11629-008-0078-z

Pant S, Samant SS (2012) Diversity and regeneration status of tree species in Khokhan Wildlife Sanctuary, north-western Himalaya. Trop Ecol 53:317–331

Paul S, Samant SS, Lal M, Ram J (2018) Population assessment and ecological niche modelling of *Carpinus viminea* wall. ex Lindl.: a multipurpose tree for conservation in the Indian Himalayan Region. Proc Indian Natl Sci Acad 84:681–694. https://doi.org/10.16943/ptinsa/2018/49345

Paul S, Samant SS, Lal M, Sharma L, Ram J (2019) Population status and habitat modelling of high value vulnerable *Ferula jaeschkeana* for conservation in North- Western Himalaya. Med Plants - Int J Phytomed Relat Ind 11:135–144

Phillips SJ, Dudík M (2008) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31:161–175. https://doi.org/10.1111/j.0906-7590.2008.5203.x

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modeling of species geographic distributions. Ecol Model 190:231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Polak T, Saltz D (2011) Reintroduction as an ecosystem restoration technique. Conserv Biol 25:424–424. https://doi.org/10.1111/j.1523-1739.2011.01669.x

Rana MS, Samant SS (2009) Prioritization of habitats and communities for conservation in the Indian Himalayan region: a state-of-the-art approach from Manali Wildlife Sanctuary. Curr Sci 97:326–335

Rana MS, Samant SS (2010) Threat categorisation and conservation prioritisation of floristic diversity in the Indian Himalayan region: a state of art approach from Manali Wildlife Sanctuary. J Nat Conserv 18:159–168. https://doi.org/10.1016/j.jnc.2009.08.004

Rana BS, Singh SP, Singh RP (1989) Biomass and net primary productivity in Central Himalayan forests along an altitudinal gradient. For Ecol Manage 27:199–218. https://doi.org/10.1016/0378-1127(89)90107-2

Rana D, Kapoor KS, Samant SS, Bhatt A (2020) Plant species conservation priority index for preparing management strategies: a case study from the Western Himalayas of India. Small Scale Forestry 19:461–481

Rana D, Kapoor KS, Bhatt A, Samant SS (2021). Community structure and species diversity of forest vegetation in a protected area of Western Himalayan region of India. Environ Dev Sustain, pp1–22. https://doi.org/10.1007/s10668-021-02020-9

Rawal RS, Gairola S, Dhar U (2012) Effects of disturbance intensities on vegetation patterns in oak forests of Kumaun, West Himalaya. J Mt Sci 9:157–165. https://doi.org/10.1007/s11629-012-2029-y

Rawat GS, Sathyakumar S, Prasad SN (1999) Plant species diversity and community structure in the outer fringes of Kedarnath Wildlife Sanctuary, Western Himalaya: conservation implications. Ind for 125:873–882

Rodríguez-Salinas P, Riosmena-Rodríguez R, Hinojosa-Arango G, Muñiz-Salazar R (2010) Restoration experiment of *Zostera marina* L. in a subtropical coastal lagoon. Ecol Eng 36:12–18

Roy PS, Roy A, Joshi PK, Kale MP, Srivastava VK, Srivastava SK, Dwevidi RS, Joshi C, Behera MD, Meiyappan P, Sharma Y (2015) Development of decadal (1985–1995–2005) land use and land cover database for India. Remote Sens 7:2401–2430. https://doi.org/10.3390/rs70302401

Samant SS, Joshi HC (2004) Floristic diversity, community patterns and changes in vegetation of Nanda Devi National Park. Biodiversity Monitoring Expedition: Nanda Devi 2003. Uttaranchal State Forest Department, Wildlife Institute of India, GB Pant Institute of Himalayan Environment and Development, HNB Garhwal University, 39–54

Samant SS, Dhar U, Rawal RS (1998) Biodiversity status of a protected area in West Himalaya: Askot Wildlife Sanctuary. Int J Sustain Dev World Ecol 5:194–203. https://doi.org/10.1080/13504509809469983

Samant SS, Joshi HC, Arya SC (2002) Studies on the structure, composition and changes of vegetation in Nanda Devi Biosphere Reserve, west Himalaya. In: Sharma JK, Easa PS, Mohanan C, Saudharan N, Rai RK (eds) Biosphere reserves in India and their management. Kerala Forest Research Institute, Peechi and Ministry of Environment and Forests, New Delhi. 133–139

Samant SS, Rawal RS, Dhar U (2006) Diversity, extraction and status of fodder species in Askot wildlife sanctuary, west Himalaya, India. Int J Biodivers Sci Ecosyst Serv Manag 2:29–42. https://doi.org/10.1080/17451590609618097

Seidl R, Thom D, Kautz M, Martin-Benito D, Peltoniemi M, Vacchiano G, Wild J, Ascoli D, Petr M, Honkaniemi J, Lexer MJ (2017) Forest disturbances under climate change. Nat Clim Change 7:395–402. https://doi.org/10.1038/nclimate3303

Shannon CE, Wiener W (1963) The mathematical theory of communities. University of Illinois Press, Urbana

Sharma A, Samant SS (2013) Diversity, structure and composition of forest communities in Hirb and Shoja catchments of Himachal Pradesh, North West Himalaya, India. Int J Bot 9:50–54. https://doi.org/10.3923/ijb.2013.50.54

Sharma S, Arunachalam K, Bhavsar D, Kala R (2018) Modeling habitat suitability of *Perilla frutescens* with Maxent in Uttarakhand: a conservation approach. J Appl Res Med Aromat Plants 10:99–105

Simpson EH (1949) Measurement of diversity. Nature 163:688. https://doi.org/10.1038/163688a0

Singh A (2007) Assessment of plant diversity and conservation status of forest vegetation in a cold desert biosphere reserve of the Western Himalaya. Thesis submitted to Kumaun University.

Singh JS, Singh SP (1986) Structure and function of the Central Himalayan Oak forests. Proc Indian Natl Sci Acad (plant Science) 96:156–189

Singh G, Padalia H, Rai ID, Bharti RR, Rawat GS (2016a) Spatial extent and conservation status of Banj oak (*Quercus leucotrichophora* A. Camus) forests in Uttarakhand, Western Himalaya. Trop Ecol 57:255–262

Singh S, Malik ZA, Sharma CM (2016b) Tree species richness, diversity, and regeneration status in different oak (*Quercus* spp.) dominated forests of Garhwal Himalaya, India. J Asia-Pacific Biodivers 9: 293–300

Singh A, Samant SS, Naithani S (2021) Population ecology and habitat suitability modelling of *Quercus semecarpifolia* Sm. in the sub-alpine ecosystem of Great Himalayan National Park, northwestern Himalaya, India. S Afr J Bot 141:158–170. https://doi.org/10.1016/j.sajb.2021.04.022

Subbiah BV, Asiija GL (1956) A rapid procedure for the estimation of nitrogen in soil. Curr Sci 25:259–260

Terribile LC, Lima-Ribeiro MS, Araújo MB, Bizao N, Collevatt RG, Dobrovolski R, Franco AA, Guilhaumon F, Lima JDS, Murakami DM, Nabout JC (2012) Areas of climate stability of species ranges in the Brazilian cerrado: disentangling uncertainties through time. Nat Conserv 10:152–159. https://doi.org/10.4322/natcon.2012.025

Thadani R, Ashton PMS (1995) Regeneration of banj oak (*Quercus leucotrichophora* A. Camus) in the central Himalaya. For Ecol Manage 78:217–224. https://doi.org/10.1016/0378-1127(95)03561-4

Thuiller W, Richardson DM, Pyšek P, Midgley GF, Hughes GO, Rouget M (2005) Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. Glob Change Biol 11:2234–2250. https://doi.org/10.1111/j.1365-2486.2005.001018.x

Troup RS (1921) The Silviculture of Indian trees (vol. 1). Clarendon Press, England

Upgupta S, Sharma J, Jayaraman M, Kumar V, Ravindranath NH (2015) Climate change impact and vulnerability assessment of forests in the Indian Western Himalayan region: a case study of Himachal Pradesh, India. Clim Risk Manage 10:63–76

Verma RK, Kapoor KS, Subramani SP, Rawat RS (2004) Evaluation of plant diversity and soil quality under plantation raised in surface mined areas. Indian J for 27:227–233

Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic soil titration method. Soil Sci 37:29–37

Yang XQ, Kushwaha SPS, Saran S, Xu J, Roy PS (2013) Maxent modeling for predicting the potential distribution of medicinal plant, *Justicia adhatoda* L. in Lesser Himalayan foothills. Ecol Eng 51:83–87. https://doi.org/10.1016/j.ecoleng.2012.12.004

Zai X, Qin P, Wan S, Zhao F, Wang G, Yan D (2009) The application of beach plum (*Prunus maritima*) to wasteland vegetation recovery in Jiangsu Province, China: seedling cloning and transplantation. Ecol Eng 35:591–596. https://doi.org/10.1016/j.ecoleng.2008.02.00